B.C. Agricultural Drainage Manual

Province of British Columbia
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B.C. AGRICULTURAL DRAINAGE MANUAL

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I INTRODUCTION

The B.C. Agricultural Drainage Manual provides information for designing farm drainage systems in British Columbia. This manual is intended as a general reference although specific drainage design criteria are included.

The following topics are covered in the manual.

Drainage Benefits

To understand the importance of drainage systems, the benefits accrued to agricultural land must be realized.

Need Indicators

Not all agricultural lands require drainage. Soil conditions, crop response and water table levels should be evaluated before a decision to drain the land is made.

Drainage Planning Requirements

A step by step approach to a farm drainage system design should be taken to ensure that the maximum benefits for the least capital cost can be achieved.

Drainage Ditch Design

Agricultural drainage systems often require ditches to convey water away from the land. Information on calculating peak runoffs, ditch size and grades is included in this manual.

Grassed Waterway Design

The Peace River, Cariboo and other areas of the province require the use of grassed waterways to remove surplus water from fields during spring melt and intense rainfall. Information on sizing, shaping and selecting the type of grassed waterway is included.

Subsurface Drainage Design

The design of a subsurface drainage system must account for soil, crop and climatic parameters. Methods of determining drain depth, spacing and size requirements are shown in the manual. Drain installation, envelope materials, blind inlets and other considerations are also presented.

Pump and Outlet Design

The success of a drainage system is dependent on having a good outlet condition. Gravity and pumping outlet designs are discussed in the manual. Pump selection, sizing and set up information is important to ensure that the design capacity of the system can be met.

Construction

There are various methods of installing subsurface drainage systems. To obtain the desired depth and grade for the soil conditions present, appropriate construction methods and machinery should be used.

Maintenance

The longevity of a drainage system is directly reflected by maintenance practices. Adequate inspection, identification of hazards and timely repair work will help to improve the life of a drainage system.

The manual is presented in metric. A conversion table is provided in Appendix E for convenience.

1.1 DRAINAGE IN B.C.

Poorly drained lands are scattered throughout B.C. Table 1.1 provides a rough estimate of poorly drained lands in B.C.

Table 1.1 Poorly Drained Lands in B.C.

Fraser Valley	50,000 hectares
Vancouver Island	4,500
Kootenays	1,000
Okanagan	3,000
Cariboo	42,000
Peace	412,000

From: Water Constraint Study
Talisman 1984

Subsurface drainage systems in B.C. from 1952-1977 amounted to approximately 3.05 million meters of drain installed. At an average 18 m spacing the area drained during this time period totals approximately 5700 hectares. Since the expansion of the drainage industry in 1977 an additional 2.75 million meters of drain tile was installed through to 1983. This represents 5200 hectares of drained land during a six year period. Figure 1.1 graphically indicates the quantity of subsurface drain installation from 1956 to 1984.

The Fraser Valley currently accounts for 60% of the subsurface drainage system installations. Vancouver Island currently makes up for 25% of the subsurface drainage work with the rest of the province accounting for 15%.

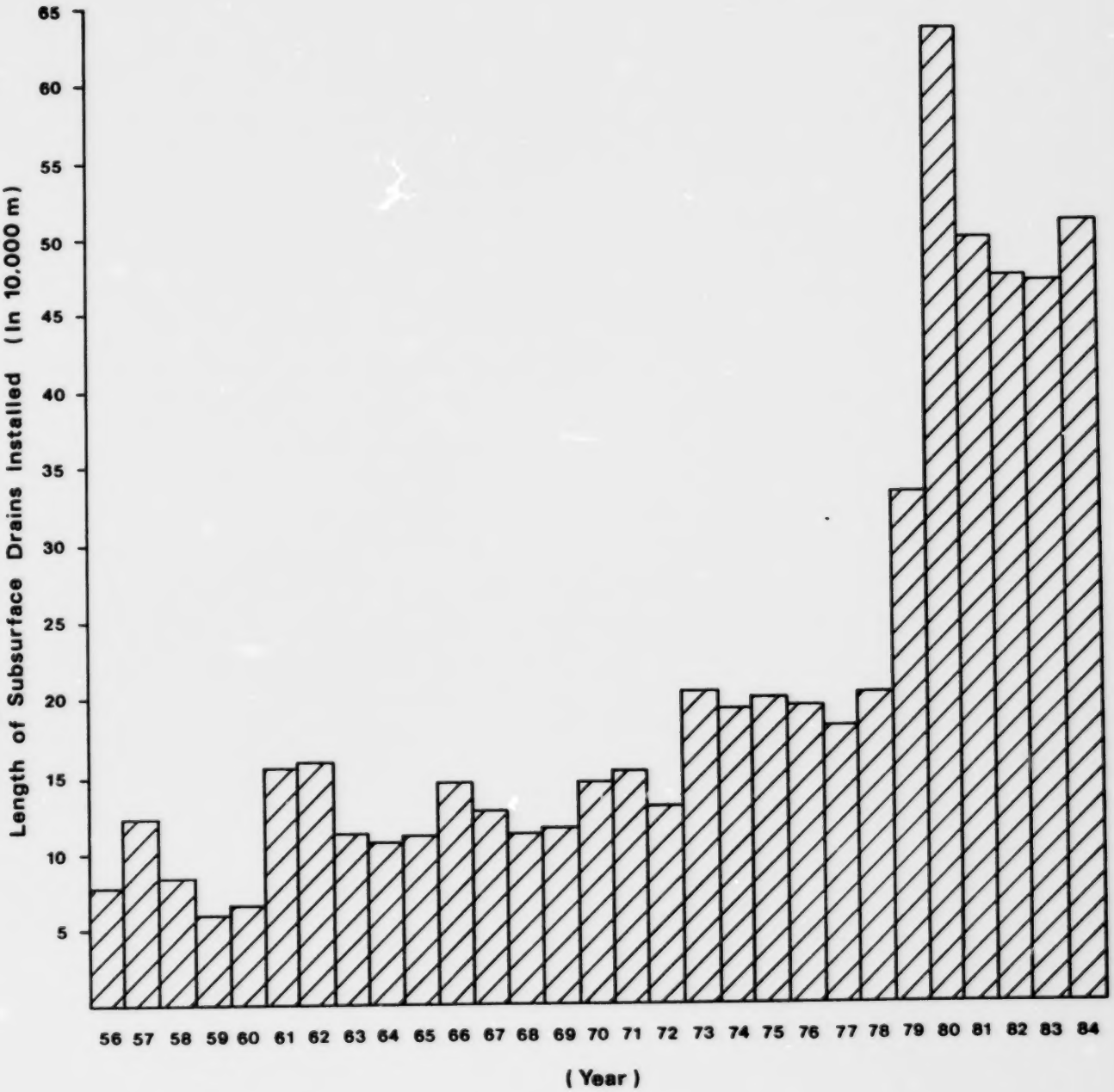


Figure 1.1 Subsurface Drain Construction in B.C.

II AGRONOMIC REQUIREMENTS AND DRAINAGE BENEFITS

2.1 AGRONOMIC REQUIREMENTS

There are four primary requirements for plant growth - air, nutrients, warmth and water. All are important and all depend to a certain extent upon water. Good drainage is required to ensure that the right amounts of each are available to the plant.

Air

Air is required in the soil for good seed germination and root growth. A good soil, air and water balance is required to promote the growth of worms and micro-organisms that enhance soil structure. A high water table restricts the soil air supply. High water tables cause plants to establish shallow rooting systems. During drought conditions, as the water table drops, shallow rooted crops are often unable to reach necessary soil moisture. A drained soil promotes deeper plant root growth by lowering the water table during excessive rainfall or spring runoff conditions. The lowered water table provides better aeration of the soil.

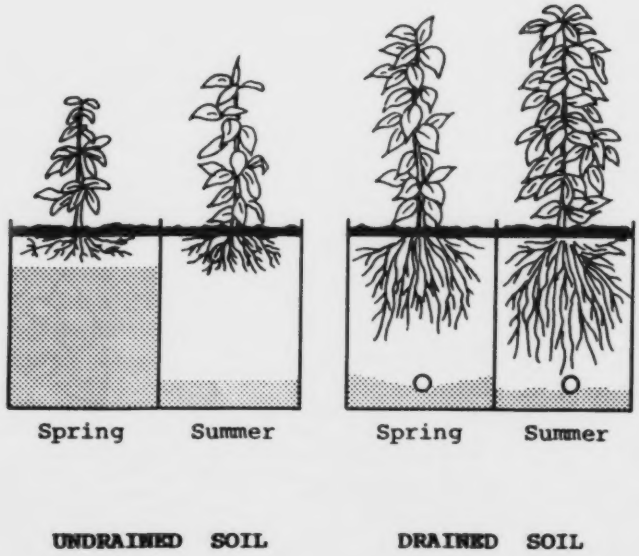


Figure 2.1 Root Development on Drained and Undrained Soil

Nutrients

Plants require the correct nutrients in sufficient amounts for optimal growth. Manure is broken down by aerobic micro-organisms and is taken up into the plants through the root system. In water-logged soils aerobic bacteria are replaced by anaerobic bacteria. Anaerobic organisms reduce manure to forms that are not available to the plant. For example, nitrates are reduced by anaerobic bacteria to forms that are lost from the soil as gas. Drainage enables plants to utilize inorganic fertilizers more effectively.

Warmth

Plants need heat to germinate and to develop to their full potential. Because of the high specific heat of water, it takes approximately five times as long to raise the temperature of a wet soil than it does a dry soil. With a drained soil the soil temperature is raised more quickly therefore increasing the number of growing days per season.

Water

Plants require the right amount of water for growth. Useful soil water for plant growth originates either from infiltration or from capillary action from the water table. Infiltration or gravitational water moves freely to fill all of the open pores in the soil. With the use of drainage the gravitational water is removed as quickly as possible to allow air to replace the water in the large soil pores. The capillary water is held as a continuous film surrounding the soil particles by means of surface tension. This water is used directly by the plant and is replaced by means of infiltration into the soil or by capillary rise from the water table. (See Figure 2.2 and 2.3)

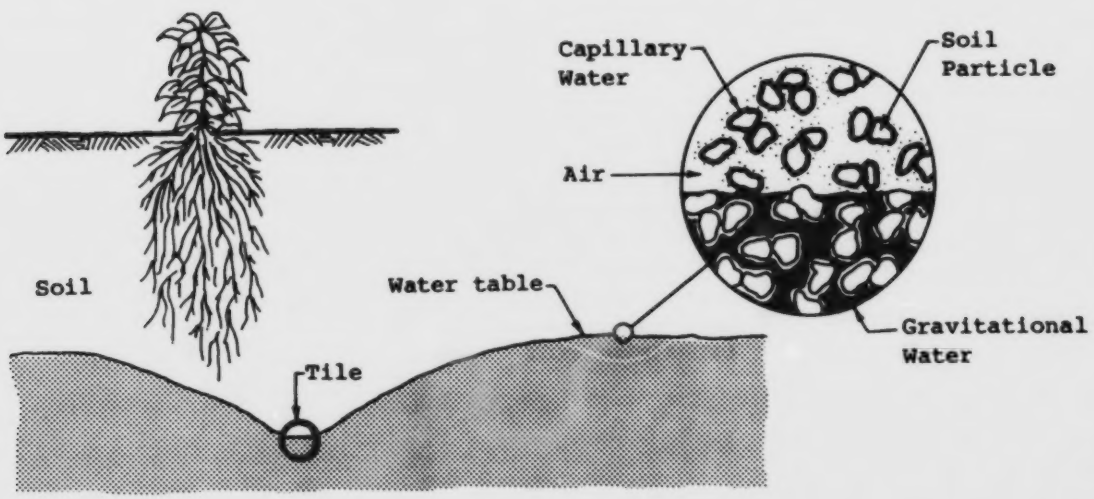


Figure 2.2 Soil Water Movement

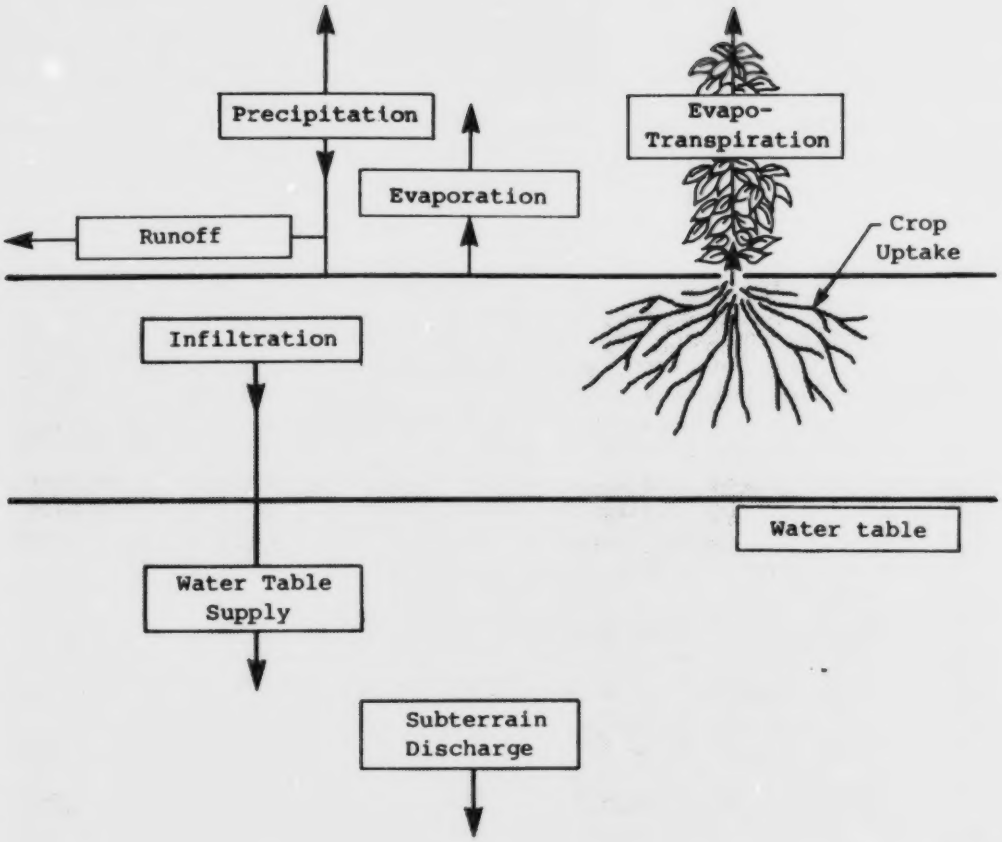


Figure 2.3 Soil Moisture Balance

2.2 DRAINAGE BENEFITS

Increased Trafficability

Trafficability is one of the most important aspects of land drainage. The decision to drain a field may be based entirely on avoiding problems of practical management during spring and autumn, when tillage operations and harvesting may be impeded because of waterlogging. Trafficability and workability depend on soil strength which is largely determined by soil water tension. Higher tension creates stronger attraction between soil particles which strengthens the soil.

In a permeable soil water tension is closely related to water table depth. A lower water table increases soil water tension and makes the soil more trafficable. Conversely, a water logged soil is not trafficable because of low soil water tension and corresponding low soil strength. The soil profile should be permeable down to the drain depth. The water table should be lowered to 0.50 m below the soil surface to give trafficable conditions. Lowering the water table to this depth also provides a good aerated zone to promote earthworm populations. Good trafficability is required early in the growing season to ensure that weed control measures can be done. Soils in poor trafficable conditions will allow weeds to overtake an emerging crop, making weed control at a later date difficult.

Optimum Rooting Depth

Water table control is necessary to allow the development of an extensive, healthy rooting system. Drainage must at least control the water table to the crop rooting depth. Table 2.1 provides information on minimum water table depths for various crops. These values are based upon effective rooting depths of the crop. It is important to realize that trafficability or other drainage requirements will most likely exceed the water table control requirements of shallow rooted crops. The values in Table 2.1 should only be used as a starting point.

Compacted layers such as pans will also restrict root growth. Pan formation results from soil compaction created by the movement of farm machinery and livestock on land under conditions where the soil is not trafficable. The compaction may reach a depth of 0.5 m, well below the bottom of the plough layer. A pan prevents plants from reaching their potential rooting depth. Shallow rooting depths require earlier and more frequent irrigation during the growing season. A good drainage system, along with proper soil management will reduce pan formation and potentially increase crop rooting depth.

Table 2.1 Minimum Water Table Depths for Various Crops

Water Table Depth (m)			
0 - 0.30	0.30 - 0.40	0.40 - 0.5	0.6 +
Tolerant Species	Shallow Rooted	Medium Rooted	Deep Rooted
Rushes	Cranberries	Strawberries	Alfalfa
Sedges	Forage Grasses	Blueberries	Raspberries
Reed Canary Grass	Red Top	Black Currants	Red Currants
	Ladino Clover	Nursery Crops	Nuts
Water Fox Tail	White Clover	Red Clover	Tree Fruit
	Vegetable Leaf Crops	Alsike Clover	Asparagus
	Spinach	Vegetable Root Crops	Corn
	Lettuce	Carrots	Grapes
	Cabbage	Parsnips	
		Potatoes	
		Beets	
		Bulbs	

Increased Crop Yield

Plants use fertilizers more efficiently in well-drained soils. Nutrient take-up is improved thereby possibly reducing application rates. Drainage allows the plant's root system to develop properly. Plants are able to draw moisture from a larger volume of soil and are therefore better equipped to withstand drought. Well-drained and aerated soils are less prone to plant diseases. Soil properly aerated warms up faster aiding in seed germination and crop establishement.

Greater Cropping Choice and Flexibility

Well drained soils offer greater choice and flexibility of crops. Land previously suitable to only high moisture tolerant crops may now be suitable for other higher value crops.

Longer Growing Season

A drainage system allows earlier tillage and seeding operations during spring conditions. The basic agronomic requirements discussed earlier are achieved sooner, giving the plant a better chance to reach its potential during the growing season.

Longer Harvest Season

Increased trafficability due to a drainage system allows for longer field operations during the fall period. The increase in opportunity days gives a better chance to harvest late crops.

Potential For Sub-Irrigation

In relatively flat lands, water control structures can be used to raise the water table for sub-irrigation. Water can be backed-up into the ditches and subsurface drains and be carried into the root zone by capillary action.

Control of Erosion By Water

Rainfall on poorly-drained, water-logged soils causes overland runoff and may carry soil particles with it. Well-drained soils have a capacity to absorb rainfall resulting in some control of water erosion.

Increased Land Value

In addition to the value of increased productivity, drainage systems increase the value of land through increased capability.

Decreased Salinity

Agricultural soils should be managed so that the presence of salts do not adversely affect crop yield and quality. Areas adjacent to salt water as well as arid and semi-arid areas commonly have crop yields depressed by salinity. Salinity can be reduced by drainage in conjunction with adequate water application using irrigation or natural precipitation.

III DRAINAGE NEED INDICATORS

3.1 WATER TABLE

Water table is defined as the upper surface of ground water. All voids below the water table are filled with water which freely respond to the pull of gravity. The level of the water table depends on the nature of soil and parent material, precipitation or seepage, physical geography and associated evapotranspiration. During storm periods the water table may approach the soil surface. The most direct method of determining drainage need is by observation of the water table depth in the soil. A well drained soil can be defined as one with a water table that does not come within 0.30 m of the soil surface, or does so briefly receding quickly to a depth of 0.50 m upon cessation of a storm event.

Figure 3.1 graphically shows the difference in water table depth throughout the year of a drained versus an undrained field with identical soil types.

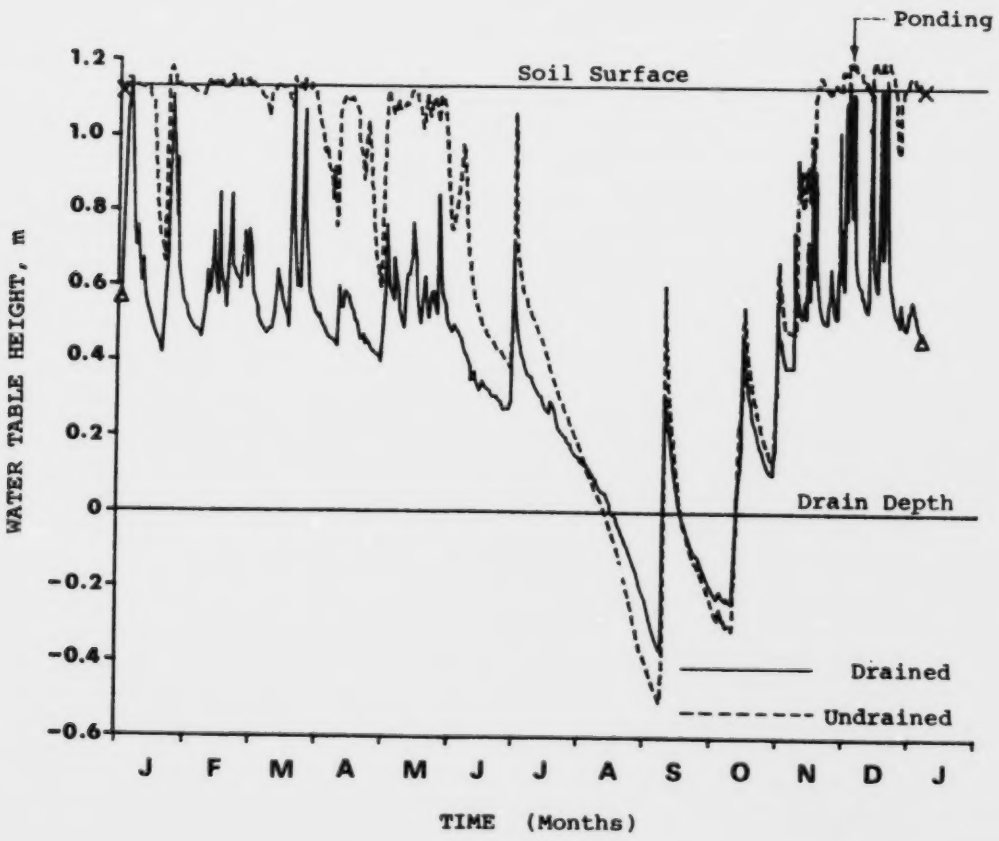


Figure 3.1 Water Table for Drained vs Undrained Soil, Delta, B.C. 1984

3.2 CROP RESPONSE

The growth of agricultural crops is adversely affected by continued saturation of the root system or by ponded water on the soil surface. Poorly drained soils exhibit many of the following features:

GERMINATION of seeds is delayed and sometimes prevented due to low soil temperature, reduced aeration, rough condition of seedbed and other associated factors.

DEVELOPMENT of crops is retarded usually in a non-uniform manner due to different drainage conditions. High ground water and resulting soil structure damage inhibits root development and causes shallow root systems.

COLOR of annual crops is usually lighter, similar to that caused by nitrogen deficiency, which is particularly evident when poor drainage conditions exist during the growing season. However, in grasses and other perennials poor drainage is characterized by dark discoloration of dying or decaying plant matter and the predominance of coarse dark colored plant species such as sedges and rushes.

YIELD of most domestic crop species is generally lower. The degree to which yields are depressed depends on the type of crop and the severity of the drainage problem.

WEEDS common to wet, swampy land include: rushes, sedges, horsetail, silverweed, mosses, smartweed, water timothy, skunk cabbage, buttercup, chickweed, cattails, tules, duckweed, water foxtail and red sorel.

DISEASES such as root or crown rot of grasses, cereals, alfalfa, clover, beans, peas, raspberries and strawberries may develop. Blueberries, apples and potatoes may show signs of collar rot, crown rot and other diseases.

3.3 SOIL CONDITIONS

Undrained soils do not provide the right amounts of air, nutrients, warmth and water required for proper plant growth. The soil will portray signs of not meeting these basic needs in many of the following ways:

COLOR - Blue, blue grey and grey (gley) are good, though not infallible, indicators of poor drainage. Shades of grey, brown and yellow blotches (mottles) in mineral soils also indicate poor drainage conditions usually caused by a fluctuating water table.

STRUCTURE - Development of the soil is usually weak or absent causing the soil to be more or less massive. Tillage operations break the soil into large, coarse clods leaving the field in a rough condition making proper seed bed preparation more difficult.

SOIL pH - In humid regions a low pH is usually associated with inadequate drainage. Poorly drained soils of arid regions often have a high pH and also a high conductivity (salt content). Salt crusts showing on soil surface indicate alkali formation which is often associated with poor drainage.

TEMPERATURE - Reduction of the water content allows the soil to warm up more rapidly. Since the specific heat of water is approximately 1.0 calories per gram and that of dry mineral soil is about 0.2 calories per gram, five times as much heat is required to raise the temperature of water than that of dry soil. Evaporation of water from a saturated soil also has a marked cooling effect because it takes approximately 580 calories of heat to transform one gram of water from a liquid to the gaseous state.

TOXICITY - Reduced iron, manganese and hydrogen sulphide may reach toxic levels. In arid regions high evaporation causes gradual accumulation of salts which may build up to toxic levels.

AERATION - Restricted or completely prevented aeration in high moisture level soils results in reduced gas exchanges. Accumulation of carbon dioxide in the soil pores and subsequent reduced oxygen supply adversely affects the uptake of water and nutrients by plant roots.

FERTILITY - Availability of nutrients is restricted and the process of denitrification is increased. Other factors detrimental to the growth of high-yield domestic crops as listed under Need Indicators contribute to a state of general low relative fertility.

3.4 SOIL EROSION

Runoff during both severe rainstorms and lower intensity storms of long duration erode away surface soil from many of British Columbia's sloping lands. Poorly drained soils do not have the capacity to store additional water and also have low infiltration rates. A properly designed subsurface drainage system is an effective means of reducing severe soil erosion problems. Figure 3.2 schematically shows one method of reducing soil erosion by using subsurface drainage systems. Contact the B.C. Ministry of Agriculture and Food for further information.

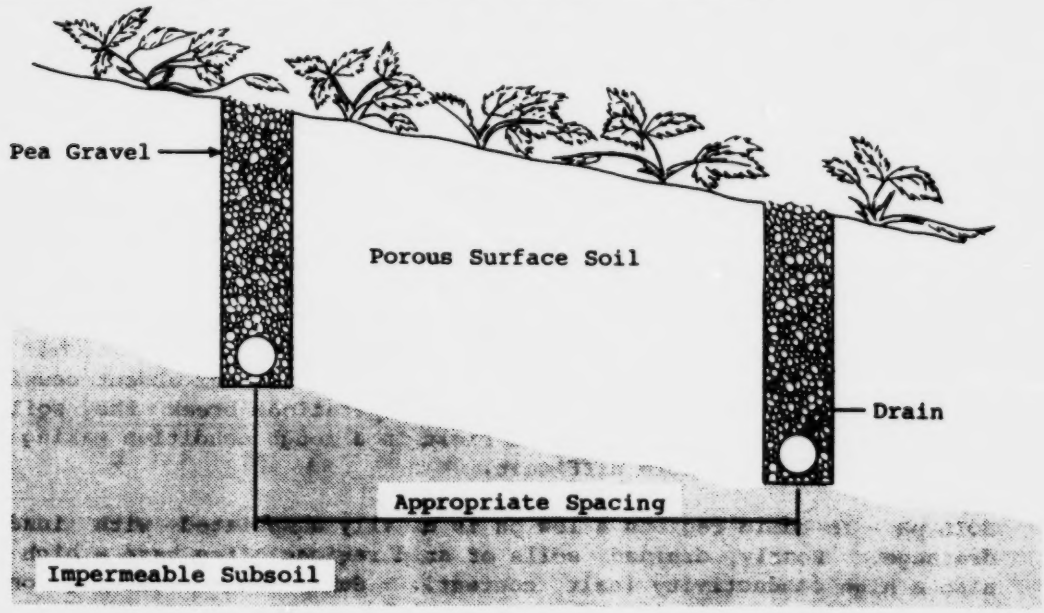


Figure 3.2 Erosion Control Method Using Subsurface Drainage

IV DRAINAGE PLANNING REQUIREMENTS

The design and installation of a good drainage system requires information on soils, crops, climate and topographical field data. The drainage plan should provide step by step information on how to construct and install a complete drainage system. The plan should include information on:

- soils
- best possible outlet location
- location, size, depth, spacing and slope of all open ditches and subsurface drains
- location of all pertinent obstructions such as buildings, trees, fences, gas, oil, water, telephone and other utility lines
- upland and surface runoff conditions

A plan allows the landowner to install the system as time, labour or finances permit. The plan provides a record for future reference and should be passed on to future landowners.

4.1 SOILS INVESTIGATION

Preliminary Survey

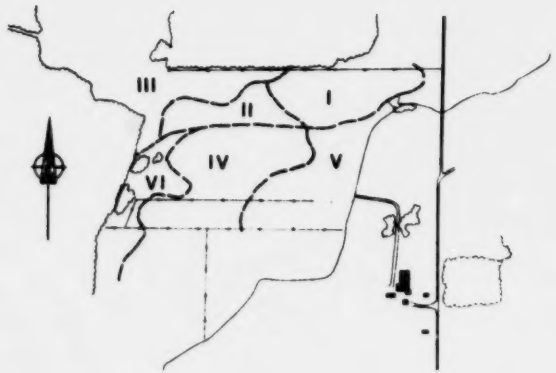
A preliminary survey should be carried out during the winter or whenever the drainage problem is evident. Visual observations of field conditions, location of poorly drained areas, topographic and soil features, land use, etc. should be made. From these observations the need for saturated hydraulic conductivity measurements and other data is determined and a preliminary evaluation of the anticipated cost and benefits can be made.

Soil Survey

A soil base map should be prepared showing land boundaries, roads, creeks and other landscape features. Soil boundaries and profile pits should also be shown. A brief description of the profile pit data and soil survey reports should be included with the soil survey report. (See Figure 4.1)

Profile pits are excavated in a number of locations. These pits are about 0.5 m wide and 1 m deep. An open type Dutch auger is used to obtain samples to a depth of about 2 m. In well defined deposits such as glacial tills where hand augering is difficult to perform, deep boring is not required. The purpose of the pits is to determine the hydrologic properties of the soil from the nature of the exposed soil profile.

SOIL MAP



DESCRIPTION

SOIL TYPE	DEPTH cm	DESCRIPTION
I	0 - 70	Humified organic material interstratified with thin lenses of mineral sediment (silt loam - clay loam).
	70 - 230+	Mesic to fibric organic macerial becoming mesic with depth, scattered wood debris.
II	0 - 10	Humified organic material.
	10 - 37	Sandy clay, reddish brown, abundant concretions, in places weak or quasi-cemented.
	37 - 70	Fine sandy clay, abundant concretions distinct mottling and gleying.
	70 - 105+	Stoney, gravelly, sandy clay very firm, strongly gleyed.
III		Not surveyed. Mostly well drained sands and gravelly materials.
IV	0 - 20	Loam - sandy loam, scattered gravels, concretionary, moderately firm.
	20 - 50	Concretionary stoney sandy clay, very firm compact.
V	0 - 30	Loam to fine sandy loam, granular.
	30 - 50	Silt loam to silty clay loam, firm and compact, occasionally weakly cemented.
	50 - 150+	Clay, firm to very firm, strongly mottled, moderately gleyed. Occasional, scattered stones.
VI		Similar to type IV soil except for higher degree of poor drainage.

SCALE 1:8,900

LEGEND: SOIL BOUNDARY; FENCE; ROAD; DITCH; UNCLEARED LAND; BUILDING

DRAINAGE SURVEY REPORT

PROVINCE OF BRITISH COLUMBIA
SOILS BRANCH
MINISTRY OF AGRICULTURE AND FOOD

SURVEY REPORT: M. Driehuyzen & D. Pedersen

PHOTO NO: 7761:258

REPORT NO: 82-08-13

NAME & ADDRESS

EXAMPLE DRAINAGE
PLAN NO. 100.448

Figure 4.1 Sample Soil Survey Report

The location of profile pits is carefully chosen so that all features of an area which may have a significant bearing on the layout or construction of a drainage system are known. Some pits will therefore be chosen at the bottom of a depression or at the top of a ridge. The number of profile pits required depends entirely on the variability of the soil, the availability of data and the experience of the investigator. The number of pits should be sufficient to enable the investigator to make a reliable assessment of all pertinent drainage features. Each profile is carefully examined for texture (using the common hand-feel method), structure, stones, gravel, hardpan, buried logs or stumps, water table depth, color and any other feature having bearing on the design or construction of the drainage system. The observed features should be recorded on the soil base map using abbreviations or symbols.

The following features should be used to evaluate the soil conditions in a profile pit:

SOIL SEPARATES are the individual particles which make up the mineral part of the soil. Soil designations are shown in Table 4.1

Table 4.1 Soil Designation

Designation	Particle Size Diameter (mm)
Very coarse sand	2.0 - 1.0
Coarse sand	1.0 - 0.5
Medium sand	0.5 - 0.25
Fine sand	0.25 - 0.10
Very fine sand	0.10 - 0.05
Silt	0.05 - 0.002
Clay	less than 0.002

U.S.D.A. Classification System

TEXTURE is the relative proportion of sand, silt and clay as shown in the texture triangle diagram (Figure 4.2). It generally is estimated in the field with the "hand feel method." The hydraulic conductivity of the soil depends to a large extent on the soil texture which is therefore one of the prime characteristics on which drainage design is based.

STRUCTURE refers to the degree of aggregation of primary soil particles into secondary units. The better structured the soil (the greater the degree of aggregation) the better its soil, air and water relationships. The type and degree of structure is determined from visual observation of the profile and manner of fracturing when breaking off segments. Structure is an important factor in the permeability of the soil, particularly in fine textured soils which require cracks and cleavages for movement of air and water.

Coarse textured soils may tolerate periods of high water table without sustaining serious damage. Fine textured soils require good structure and may receive extensive structural damage from poor drainage.

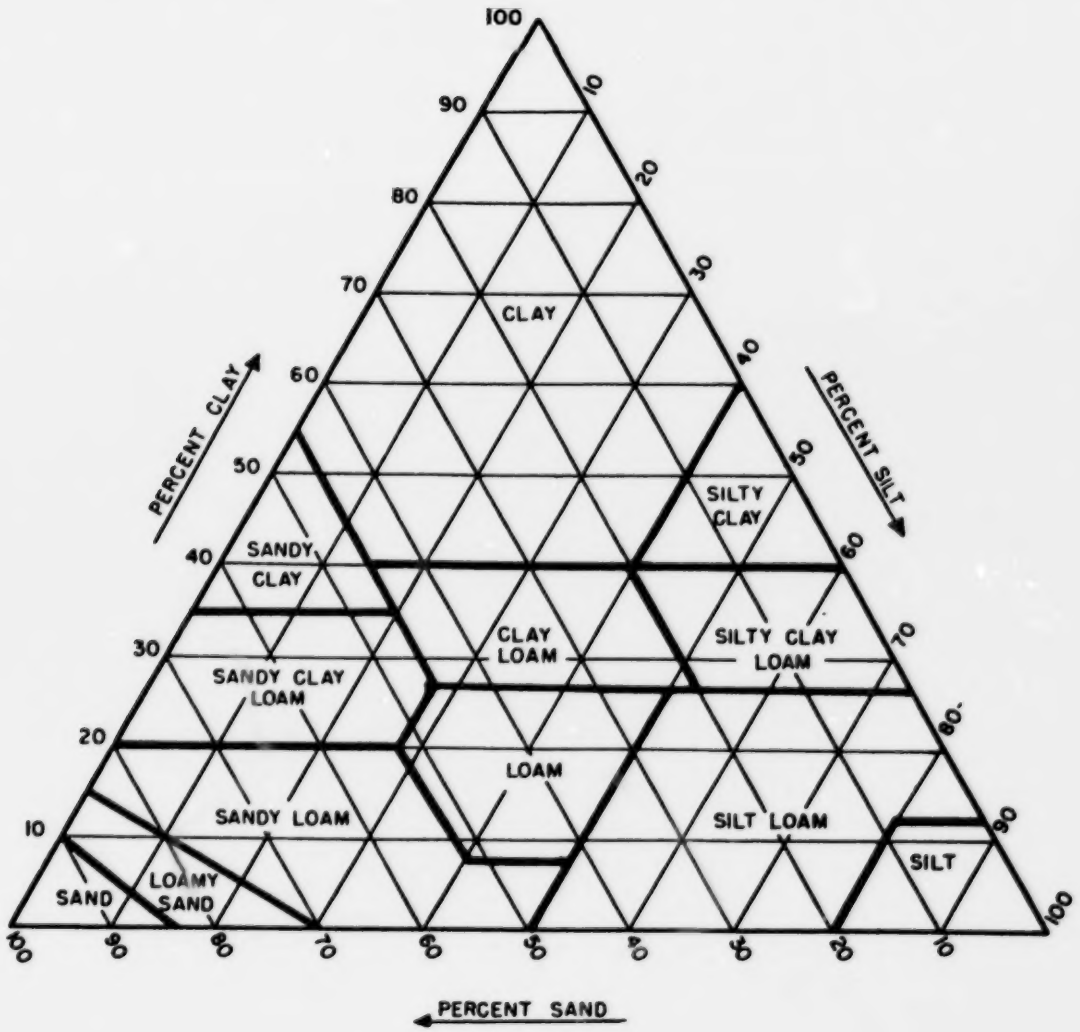
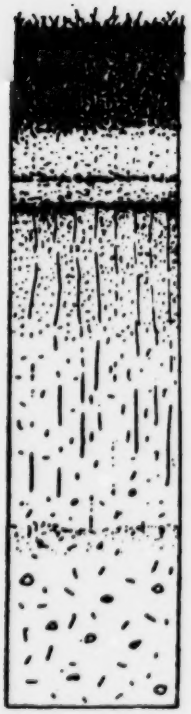


Figure 4.2 Soil Texture Triangle

SOIL PROFILE is a vertical section of the soil through all its horizons and extending into the parent material. The division of horizons is based on the extent and kind of weathering processes that have acted on the soil. Basically three main mineral horizons are recognized which are designated "A," "B," and "C" (Figure 4.3). Combinations and variations can occur.

Profile features of particular importance in drainage design are the depth and nature of textured layers, the kind and extent of structural features, the presence of stones, logs, peat or flow sand and the depth of a "hardpan" or impermeable layer.



-- L-F-H	Organic horizons
-- Ah	Mineral horizon of organic matter accumulation
-- Ae	Horizon of eluviation (leaching)
-- AB,A & B, BA	Transitional horizons
-- B	Horizon of illuviation (accumulation)
-- BC, CB	Transitional horizons
-- Ck	Horizon enriched with carbonate
-- C	Horizon affected little by soil-forming processes

Figure 4.3 Soil Profile

INFILTRATION - The process of water entering the soil surface depends on texture, structure and type of soil cover. If the infiltration rate of the soil is lower than the rate of precipitation, surface drainage or a combination of surface and subsurface drainage should be used or the infiltration rate must be increased by providing the soil with a good cover or by using other appropriate management practices. Table 4.2 provides maximum infiltration rates for various soil textures at saturation.

Table 4.2 Maximum Infiltration Rates At Saturation

Textural Class	Grass Sod (mm/hr)	Cultivated (mm/hr)
Sand	7.5	4.2
Loamy sand	6.7	3.3
Sandy loam	4.6	2.5
Fine sandy loam	4.2	2.5
Loam	3.3	2.1
Silt loam	3.3	2.1
Clay loam	2.9	1.7
Clay	2.5	0.8
Organic soils	5.0	5.0

Hydraulic Conductivity

The hydraulic conductivity is the rate of flow of water through soil assuming a hydraulic gradient of unity. The hydraulic conductivity depends on the size, continuity and total volume of soil pores, which in turn depends on texture and structure. Units for hydraulic conductivity in this manual are in m/day.

The saturated hydraulic conductivity (K) must be calculated for the different soil types to determine the subdrain spacing and depth requirements. In conjunction with the soil survey, the drainage system layout can then be determined.

If the hydraulic conductivity is to be measured, the auger hole method is suggested. This method is limited to areas where a high groundwater table exists and in soils where an auger hole of known dimensions can be maintained throughout the test. Refer to Appendix A for a description of the auger hole method of measuring and calculating hydraulic conductivity. Table 4.3 indicates a range of hydraulic conductivities for some common soil textures shown.

Table 4.3 Soil Hydraulic Conductivity

Soil	Hydraulic Class	Hydraulic Conductivity m/day	Approximate * Drain Spacing m
Clay	Very Slow	< 0.03	10-15
Clay loam	Slow	0.025 - 0.10	10-20
Loam	Mod. slow	0.10 - 0.50	15-30
Fine sandy loam	Mod.	0.50 - 1.50	20-30
Sandy loam	Mod. rapid	1.50 - 3.00	30-40
Peat and muck	Rapid	0.10 - 6.0	10-40

*To be used as a guide only.

Soil Management Practices

The final aspect to investigate during the soil survey is the present soil management practices. The effectiveness of a drainage system is directly influenced by these practices. This applies particularly to fine textured soils which are most susceptible to compaction and general structural breakdown. Management practices which maintain or improve the effectiveness of a drainage system include the following:

- limited land usage when the field is saturated.
- fine textured soils which are compacted and difficult to drain are kept in permanent pasture or some other permanent ground cover crop.
- tilled land be protected in winter by cover crops.

- soil fertility must be kept at a high level with fertilizer and manure to encourage extensive and deep rooting.

- the organic matter content of the soil must be kept high through application of manure, green manure, compost or other organic materials.

- subsoiling

Inquiries regarding soil management practices, soil surveys and parameters may be forwarded to the Soils Branch, B.C. Ministry of Agriculture and Food.

4.2 TOPOGRAPHIC SURVEY AND BASE MAP

Topographic surveys are normally required for the design of both surface and subsurface drainage systems. The purpose of the survey is to develop a topographic map showing important elevations and key physical features of the property. Used in conjunction with the soils survey it enables the designer to layout the system and provide the necessary construction details.

Various types of field survey methods are used depending on the equipment available, the surveyor's preference, and the detail required. Stadia-level or transit surveys are commonly used.

Preliminary Assessment

As a first step, obtain any existing mapping for the problem area. Air photos are often very useful in preliminary assessments of the problem and to augment survey data. They are readily available for most areas of B.C. To obtain airphotos for a particular piece of property, send the legal description of the property to:

Ministry of Environment
M.A.P.S. B.C.,
Parliament Buildings,
Victoria, B.C.
V8V 1X5

Airphoto enlargements are available. In properties involving substantial areas of land development (e.g. land clearing and reclamation) and drainage of irregularly shaped fields, airphoto enlargements can be used as base maps for plotting the survey and layout data.

Topographic Survey

Before beginning the survey, the crew should walk the property with the farmer with airphotos or other maps in hand. The farmer or landowner will often have had years of experience to relate to the drainage problem. Discuss with him the normal and high water levels in the adjacent ditches, streams and poorly drained areas. Locate existing and potential outlets, the property boundaries, all problem areas, and any other important topographic features that should be included in the survey.

Suggested survey information and procedure is as follows:

(a) Start the survey from an existing permanent geodetic bench mark, if located within a reasonable distance. The location of these bench marks can be obtained from:

Ministry of Environment,
Surveys and Mapping Branch,
Supervising Surveyor,
Field Operations Division,
553 Superior Street,
Victoria, B.c.

(b) Mark a permanent bench mark on concrete footings of existing buildings or set a new bench mark stake. Make a detailed note and description of the location of this bench mark.

(c) Survey the farm on an approximate grid of 30 m x 30 m. On level or uniform topography this grid may be increased. On hilly or irregular fields the grid spacing should be reduced. Spot readings of erratic features should be taken as well. The field data should be sufficient to provide an accurately contoured topographic map. Contours at 0.5 m intervals are common, with 0.25m intervals used on very level sites.

(d) Record the following:

- Elevations and locations of ditch bottoms and banks. These may be required for drain outlets. Data taken here should be adequate to plot an accurate ditch profile.

- Ditch water levels should be taken at regular intervals.

- Determine field and property boundaries (i.e. fences, etc.). It may be necessary to design the system around these constraints.

- Existing culvert diamaters, invert elevations and conditions should be noted.

- Existing buildings trees, rock out croppings, power poles and other obstacles.

(e) Establish temporary bench marks throughout the farm in locations convenient for the start of construction.

(f) Close the survey by taking a reading back to the permanent farm bench mark. Although a high level of horizontal accuracy is not required, because of the frequently low grades in agricultural land drainage, good vertical accuracy is required.

Calculations and Plotting

Complete the survey calculations in the field book checking each calculation of elevation. Plot the data to suit the topography and the size of the drafting paper. Use a standard scale such as 1:1000, 1:1500 or 1:2000 (1:1200 is an acceptable although not standard ratio scale).

Draw the topographic contour lines, ditches and other relevant information. Contours should be drawn lightly so that the drainage design can be super imposed onto the topographic base map.

4.3 DESIGN PARAMETERS

Crop Flood Tolerance

Regional Drainage Channel Design Criteria

Design criteria for flows in surface drainage channels may be dependent upon season and cropping pattern since tolerance to flooding varies. Determination of design criteria for flooding is somewhat site specific. The following table indicates suggested minimum design criteria based on maximum allowable flooding by season for forage and corn lands for regional drainage projects in the Lower Fraser Valley:

Table 4.4 Minimum Flood Tolerances for the Lower Fraser Valley

Season	Maximum Allowable Flooding (1 in 10 year return period)*
Winter (Nov.-Feb.)	7 days
Spring (Mar.-Apr.)	1 day
Summer (May-Aug.)	0 day
Fall (Sept.-Oct.)	1 day

*A 1 in 10 year return period is defined as a storm that will likely only occur once every 10 years.

Crop tolerance to flooding in the winter is significantly greater if annual crops such as vegetables are grown. Most vegetable crops are harvested before winter flooding occurs, therefore existing crop damage is reduced. Degradation of the soil structure due to the flooding will still occur however, which may effect crop yields in subsequent years. Elimination of flooding is the optimal condition but due to economic constraints some flooding may have to be tolerated. The Water Management Branch, B.C. Ministry of Environment recommend the following minimum design criteria for small watersheds in the Lower Fraser Valley (Wilson 1980):

- A base flow of 76 m^3/day/ha should be used in areas with an average monthly precipitation in winter of 175 to 230 mm. This value should be modified for areas with either higher or lower average monthly winter precipitation rates.

- The ditches should be sized to provide a freeboard of 1.2 m from base flow levels for level land requiring subsurface systems.

Where large portions of the watershed are at a grade of 0.05% or less, culverts should be sized to handle a storm flow of 430 m^3/day/ha. A 5 day, 10 year return period winter storm in the Lower Fraser Valley has a precipitation rate of approximately 200 mm. Sizing culverts to this criteria will limit flooding to 5 days for a 5 day, 10 year winter storm.

Large drainage schemes involving substantial capital expenditures will warrant more detailed hydrological investigations to develop more accurate design criteria. See Chapter 5 for further information on surface drainage system design.

Subsurface Drainage System Design Criteria

The objective of a subsurface drainage system is to lower the water table to improve crop production. A subsurface drainage system should take into account the soil structure requirements and the flood tolerance of specific crops.

The drainage requirement should be based on:

- the amount of water to be removed (drainage coefficient)
- the depth of the water table
- the minimum rate at which the water table should be lowered

Any flooding will damage soil structure and crop production to some degree. However, during heavy precipitation events, some flooding may occur even on relatively well drained soils. To minimize soil structural damage, drainage systems should be designed so that 48 hours after the cessation of a storm rainfall event the water table is approximately 0.50 m or more below the soil surface.

Crop flood tolerances are shown in Table 4.5. If drainage systems are designed to prevent soil degradation crop damage will also be prevented. Where regional drainage systems do not provide an adequate outlet, on-farm ditches and pumps may be required to prevent flooding and the resulting soil and crop damage.

Table 4.5 Minimum Crop Tolerances to Saturated Soils

Crop:	Winter	Growing Season	
		Spring & Fall	Summer
Vegetables (Annual Crops)	7 days	1	0
Raspberries, Strawberries	1	1	0
Tree Fruits	1	1	0
Blueberries	4	1	0
Forage Crops	7	3	0

Chapter 6 provides further information on subsurface drainage system design.

Climate

The need for drainage in B.C. is generally related to climatic factors. Although some areas in B.C. require drainage because of excessive irrigation, high water tables due to increased lake or stream levels, or flooding caused by spring funoff, most of B.C.'s drainage requirements result due to excessive precipitation.

The drainage system designer must decide which season yields the peak design criteria. Appendix C provides climatic data on rainfall intensities, duration and frequencies for selected locations in B.C. The preceding section on Crop Flood Tolerances also provides general design criteria based on climatic factors. Chapter 5 and 6 provide additional information on drainage system designs using climatic factors.

Economic Considerations

Land which is wet during prolonged periods of time normally cannot be farmed profitably. Under extreme conditions cropping is not feasible at all and drainage of such areas constitutes a significant benefit which is similar in magnitude to the economic value of a similar, well drained piece of land. However, drainage conditions vary from extremely poor to well drained and the economic benefits from drainage vary accordingly.

Aside from direct measurable yield increases there are other benefits such as trafficability, timeliness, choice of crops and diminished danger of crop loss which translate into enhanced economic benefits.

The economic benefits of a drainage system should be evaluated before proceeding with construction. If an economic return is not achieved for the design approach taken, the drainage system proposal should be reevaluated. The following example portrays a simple economic statement. **This example is for a specific situation, costs and benefits will vary depending on site specific criteria.** Further information regarding economic analysis of drainage systems can be obtained from the Economics Branch, B.C. Ministry of Agriculture and Food.

Example - **Economic Benefit for Forage Production***

Assumptions:

Added Crop Production	- extra yield 3.4 tonne/ha
Market value of local hay	- $130/tonne
Cost of drainage	- $1000/ha
Interest rate	- 10%

Reseeding changed from 4 years to 6 years.
No change in fertilizer rate.

Advantages			Disadvantages		
Added Annual Returns			Added Annual Costs		
3.4 tonne hay/ha x $130/tonne	=	$442/ha	Harvesting		
			Fuel, oil, repairs	=	$9/ha
			Labour	=	$9/ha
			Depreciation	=	$8/ha
Reduced Annual Costs					
Reseeding	=	$3/ha	Drains		
			Depreciation $1000/30 years	=	$33/ha
			Interest (average) ($1000/2) x 10%	=	$50/ha
			Reduced Annual Returns	=	0
TOTAL ADVANTAGES	=	$445/ha.	TOTAL DISADVANTAGES	=	$109/ha

The net advantage of the drainage system works out to be $336.00 per hectare.

***Note that the above example is for explanatory purposes only. Actual costs and benefits will vary for site specific situations.**

4.4 FISHERY AND ENVIRONMENTAL REQUIREMENTS

When planning to correct drainage problems on farmland, be aware that improvements may affect existing fisheries or water resources.

Before undertaking drainage improvements, approval must be obtained from the Water Management Branch of the B.C. Ministry of Environment. This ensures that planned improvements have considered the management and preservation of water and fisheries resources.

If intending to permanently alter or annually maintain a stream to protect property or to facilitate the reclamation, drainage or other improvements of land, either (1) a land improvement licence where annual improvements are required, or (2) an approval for one-time improvements must be obtained. Both are issued by the Water Management Branch of the B.C. Ministry of Environment, under the Water Act.

Canada's Fisheries Act requires that any activity that may harmfully alter, disrupt or destroy fish habitat in a stream, ditch, diversion or any other water body must receive permission from the Department of Fisheries and Oceans.

Failure to comply with provisions of either of these Acts may result in significant fines and/or imprisonment. Questions regarding provisions of these Acts should be directed to your local office of the B.C. Ministry of Environment or Canada Department of Fisheries and Oceans.

Providing these agencies with a well planned proposal for the development of drainage system for farmland in most cases will receive approval. If necessary, terms and conditions may be set for the timing of improvements and measures required to reduce harmful effects such as siltation. The approval process may be lengthy, from 3 to 6 months. Due to spawning and rearing cycles of fish, work in and about a stream which could affect the fisheries resources may only be allowed during certain periods. Planning improvement programs at least one year in advance will allow for delays.

Discussions with personnel from the Water Management Branch, Fish and Wildlife Branch, as well as Fisheries and Oceans Canada regarding channel work proposals is suggested. They can advise on potential water or fisheries management conflicts and, where possible, suggest plan modifications.

V DITCH AND WATERWAY DESIGN

Surface drainage removes water from the soil surface but does not lower the water table in the soil profile. In surface drainage, land surfaces are modified as necessary to allow for gravitational flow of water to an outlet. Flow may be overland or through open ditches and channels. The rate at which the water must be removed from the land is a function of drainage outlet, crop tolerance to flooding, and the source of the excess water. Ditches and waterways are integral parts of surface drainage systems.

Design of surface drainage systems is largely dependent upon topography. Accurate survey information is therefore necessary. A survey will establish the outlet control elevation as well as elevations of low areas, culverts, bridges and weirs. The first step in surface drainage systems is to calculate the watershed area and the peak runoff that might occur.

5.1 PEAK RUNOFF ESTIMATION FOR SMALL AGRICULTURAL AREAS

For small agricultural areas Table 5.1 may be used to determine peak runoff. This table should be used only for situations where the entire watershed is agricultural land. If upland runoff from woodlands, urban or industrial areas enters the agricultural area, this table cannot be used. In order to achieve a good outlet for a subsurface drainage system the ditch size required may be deeper than the depth determined by the peak runoff requirements shown in this table. **A designer must therefore exercise caution when using Table 5.1 for designing ditches on small agricultural areas.**

Appendix B explains peak runoff determination using the rational and SCS methods. These methods should be used for large watersheds or for areas that are affected by upland runoff.

Table 5.1 Peak Runoff for Small Agricultural Areas

Region	Peak Runoff $m^3/sec/ha$
Vancouver Island	0.0060
Gulf Islands	0.0060
Lower Fraser Valley	0.0060
North Side of Fraser Valley	0.0080
Upper Fraser Valley (Agassiz)	0.0090
Pemberton	0.0120
Kootenays	0.0050
Okanagan	0.0040
Cariboo	0.0060
Peace River	0.0070

5.2 DRAINAGE DITCH DESIGN

Ditch Capacity

The Manning formula may be used to calculate the capacity of a drainage ditch.

$$Q = \frac{R^{2/3} \times S^{1/2} \times A}{n}$$

where Q = flow rate, m^3/s

V = flow velocity, m/s

R = hydraulic radius $= \frac{A}{P}$, m

P = wetted perimeter

See Table 5.5 for hydraulic radius and wetted perimeter of various channel sections

A = cross-sectional area of the ditch at right angles to the line of flow, m^2

S = slope of the ditch, m/100m

n = Manning's roughness coefficient (see Table 5.2)

Table 5.2 A Guide for the Selection of Roughness Coefficients for Design of Drainage Ditches

Hydraulic Radius (m)	n
Less than 0.75	0.045 to 0.040
0.75 to 1.2	0.040 to 0.035
1.2 to 1.5	0.035 to 0.030
Greater than 1.5	0.032 to 0.030

Ditch Velocity

Open channels are designed for minimum scour and deposition of sediments. Designers should select velocities that are neither excessively erosive nor so low as to favour large amounts of sediment deposition. Table 5.3 provides a guide to maximum allowable channel velocities.

Table 5.3 Suggested Maximum Allowable Velocities in Open Channels.

Soil Texture	Velocity (m/s)
Sand, loamy sand, sandy loam	0.75
Silt loam, loam	0.9
Sandy clay loam, sandy clay	1.0
Clay loam, silty clay loam	1.2
Silty clay	1.5
Fine gravel, cobbles	1.5
Graded mixture silt to cobbles	1.7
Coarse gravel, hardpans	1.8

Side Slope Stability

Side slope depends on soil stability. Generally, the less steep the side slope, the more stable the ditch bank. The side slopes shown in Table 5.4 may be used as a guideline. Rip rap may be required on some soil conditions to reduce sloughing.

Table 5.4 Suggested Side Slopes for Open Ditches

Soil	Side Slope (Horizontal to Vertical)
Sand	2.5 : 1
Sandy Loam	2.0 : 1
Clay or silt loam	1.5 : 1
Clay	1.0 : 1
Peat and muck	0.5 : 1

Channel Grade

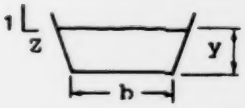
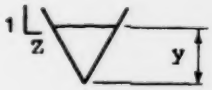
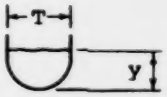
The grade of a channel should be as uniform as possible. Generally, the selection of grade is limited due to limited land slope and outlet elevation. The grade should be as steep as possible provided that the maximum allowable flow velocities are not exceeded.

Recommended designed grades are from 0.1% to 0.3% and should never be less than 0.05%.

Channel Cross Section

The cross section of a ditch is designed to meet the combined requirements of capacity, velocity, depth, side slope and bottom width. Generally, a trapezoidal cross section as shown in Table 5.5 is used and a minimum bottom width of 0.6 meters is recommended.

Table 5.5 Geometric Elements of Various Channel Sections

Channel Type		Area (A)	Wetted Perimeter (P)
Trapezoid		$by + zy^2$	$b + 2y\sqrt{1 + z^2}$
Triangle		zy^2	$2y\sqrt{1 + z^2}$
Parabola		$2/3\ Ty$	$T + \frac{8y^2}{3T}$

The hydraulic radius of the channel can be calculated by the formula:

$$\text{Hydraulic Radius } R = \frac{A}{P}$$

Example **Ditch Size Calculation**

Calculate a ditch size for the example described in Appendix B

From Appendix B - Peak Runoff $Q = 2.5\ m^3/sec$ (calculated for this example)

Table 5.3 - Maximum velocity $V = 0.9$ m/sec

Table 5.4 - Side Slope $= 1.5:1$

Desired Grade $S = \frac{0.1}{100} = 0.001$

A trapezoidal channel is to be selected. The minimum area required to remain within a permissible velocity is:

$$A = \frac{Q}{V} = \frac{2.5\ m^3/sec}{0.9\ m/sec} = 2.78\ m^2$$

From Table 5.5 $A = by + zy^2$ Z = side slope, b = bottom width, y = channel depth

1st TRIAL

Select a bottom width of 1 m — $b = 1.0$ m
channel depth of 1.1 m — $y = 1.1$ m
side slope — $z = 1.5$

Cross Sectional Area

$$A = (1.0)(1.1) + 1.5(1.1)^2$$
$$A = 2.92 \text{ m}^2$$

From Table 5.5 $P = b + 2y\sqrt{1 + z^2}$

$$= 1.0\text{m} + 2(1.1)\sqrt{1 + (1.5)^2} = 4.97 \text{ m}$$

Hydraulic Radius $R = \frac{A}{P} = \frac{2.92}{4.97} = 0.59$

From Table 5.2 $n = 0.045$ for $R = 0.59$

$$Q = \frac{R^{2/3} \times S^{1/2} \times A}{n}$$

$$Q = \frac{(0.59)^{2/3} \times (0.001)^{1/2} \times 2.92}{0.045}$$

$$Q = 1.44 \text{ m}^3/\text{sec}$$

A trial and error approach is required in order to match the channel capacity to the peak runoff expected. The channel size is selected, the flow capacity calculated and a comparison made. The calculated channel capacity must always be equal or slightly exceed the anticipated peak runoff.

	b	y	A	P	R	n	Q
1st Trial	1.0	1.1	2.92	4.97	0.59	0.045	1.4
2nd Trial	1.0	1.5	4.88	6.41	0.76	0.04	3.2
3rd Trial	1.0	1.25	3.59	5.51	0.65	0.043	2.0
4th Trial	1.0	1.35	4.08	5.87	0.70	0.041	2.5

Solution

The ditch size required to carry 2.5 m^3/sec for the example in Appendix B is:

bottom width = 1.0 m
channel depth = 1.35 m
side slope = 1.5:1
grade = 0.001

5.3 GRASSED WATERWAYS

Grassed waterways are natural or constructed waterways vegetated for safe disposal of runoff from fields or diversions. Since the primary purpose of a grassed waterway is the removal of surplus water, consideration of forage production should be secondary. Vegetated waterways can be used for the following situations:

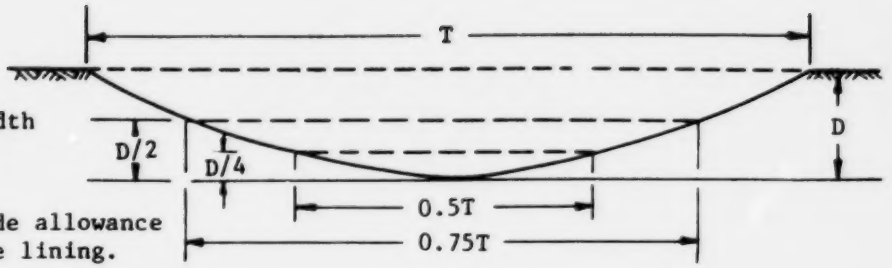
- as outlets for diversions
- as outlets for subsurface and surface drainage systems on sloping land.
- to remove excess water collected by roadway ditches
- to rehabilitate natural draws carrying runoff water

A grassed waterway requires a proper shape and vegetative cover in order to provide satisfactory performance. To ensure a long lasting effective waterway the following points should be considered:

- all flow should be diverted from the waterway during establishment period
- prolonged flow should be carried in a subsurface drainage system or in a surface protected section such as a stone center. See Figure 5.2
- Maintain a good vegetative cover by performing any maintenance work required
- use as many good conservation measures on the watershed as is practical to reduce erosion and siltation problems in the waterway.

Waterway Cross Sections

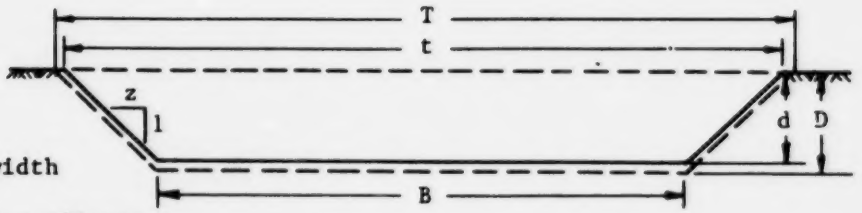
Grassed waterways are generally constructed to three general shapes: parabolic, trapezoidal, or triangular. Table 5.5 provides geometric elements for these channel shapes. Parabolic waterways are most common and is the shape ordinarily found in nature. Most trapezoidal waterways tend to revert back to a parabolic cross section.



T = design top width
D = design depth

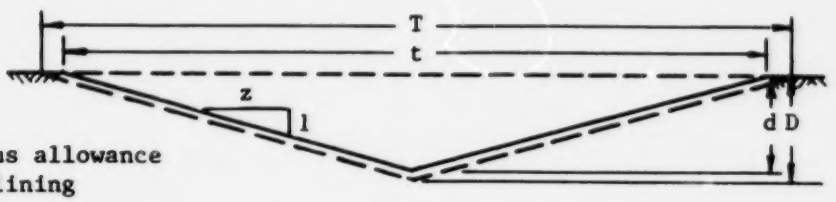
Both values include allowance for the vegetative lining.

PARABOLIC CROSS SECTION



B = design bottom width
d = design depth
D = design depth plus allowance for vegetative lining
t = design top width
T = design top width plus allowance for vegetative lining
z = side slope ratio

TRAPEZOIDAL CROSS SECTION



d = design depth
D = design depth plus allowance for vegetative lining
t = design top width
T = design top width plus allowance for vegetative lining
z = side slope ratio

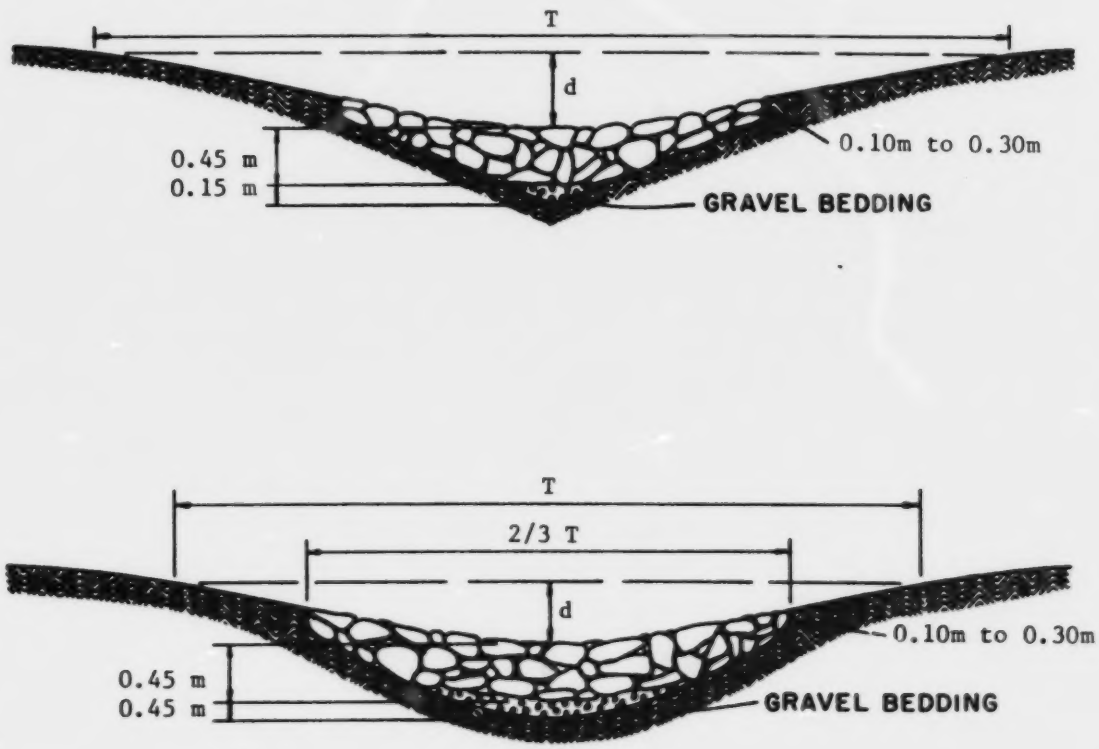
TRIANGULAR CROSS SECTION

From U.S. Soil Conservation Service

Figure 5.1 Waterway Cross Sections

Waterways with Stone Centers

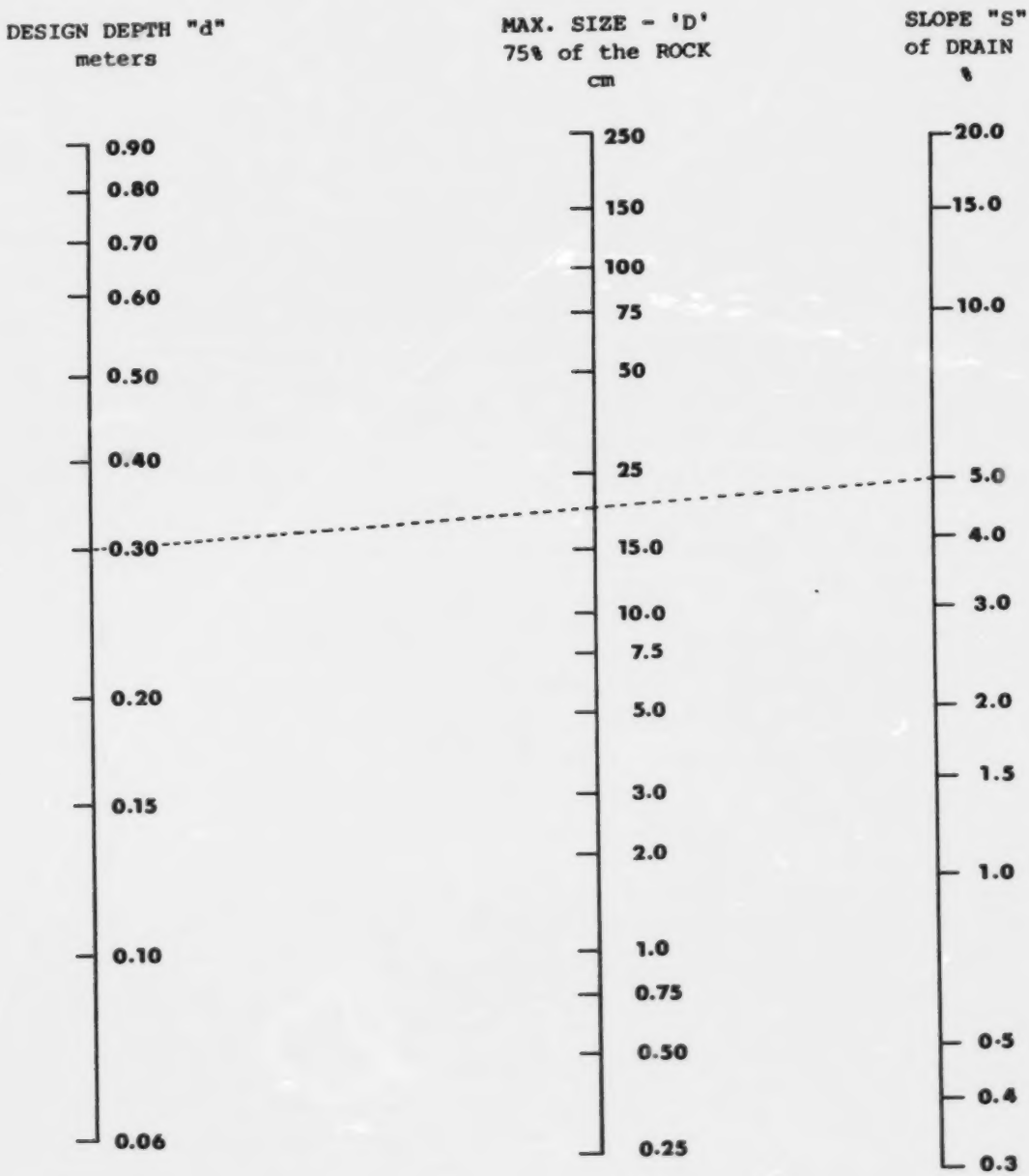
In situations where excessive or prolonged runoffs occur a waterway with a stone center should be considered.



From U.S. Soil Conservation Service

Figure 5.2 Waterways with Stone Center

Depending on the design depth and slope of the waterway various stone sizes should be selected. Situations that require stone centers will have very high runoff potential. It is recommended that professional advice be obtained before proceeding with a grassed waterway in these situations. Figure 5.3 provides information on stone size in relation to waterway slope and flow depth.



EXAMPLE: "d" = 0.30 m "S" = 5%
Place straight edge at "d" value in DESIGN DEPTH column and at "S" value in SLOPE column. Read rock size in middle column 20 cm.

FOR DESIGN: 25% of the rock by volume should be in sizes of 20 cm or slightly larger. The remaining 75% or less should be of well graded material, smaller than 20 cm, including sufficient sands and gravels to fill the voids between the larger rock.

Figure 5.3 Stone Size Determination for a Stone Center Waterway

Grassed Waterway Design

Grassed waterways are designed to discharge the peak flow expected from a 10 year frequency storm. Section 5.1 provies procedures on calculating peak runoffs. The capacity of a grassed waterway is calculated by using Mannings formula:

$$Q = \frac{R^{2/3} \times S^{1/2} \times A}{n}$$ See Section 5.2 for symbol designations

For a grassed waterway the value of the roughness coefficient n varies with VR. The term VR is a product of flow velocity and the hydraulic radius. The permissible velocity of a grassed waterway can be obtained from Tables 5.6 and 5.8

The vegetative retardance of a grassed waterway is determined by the type of vegetal conditions. Tables 5.7 and 5.9 indicate retardance values for various grass covers and conditions. The roughness coefficient n can be determined from Figure 5.4 once the vegetal retardance, permissible velocity and hydraulic radius have been obtained.

Most vegetation in a waterway does not exceed 0.45 m in height and may be shorter at other times. The designer must select a retardance value that is indicative of the grassed waterway condition during the time of peak runoff. The channel design should be checked for capacity where vegetation gives the highest retardance to see if it can accommodate peak flow.

Table 5.6 Maximum Velocities for Erosion Resistant Soils

Maximum Velocity	Waterway Condition
1 m/sec	only a sparse vegetative cover can be established or maintained
1 - 1.25 m/sec	normal conditions where vegetation is established by seeding
1.25 - 1.5 m/sec	dense, vigorous sod is obtained
1.5 - 1.8 m/sec	well established sod of good quality
1.8 - 2.1 m/sec	sod of excellent quality and special circumstances dictate that flow cannot be handled at a lower velocity

Grass Seed Mixtures for Waterway Designs

Suitable grass mixtures for B.C. conditions must be selected to ensure a hardy stand, good germination and erosion protection. Not all of the grasses shown in Tables 5.8 and 5.9 will provide desirable vegetative covers in grassed waterways for B.C.'s climate. Table 5.7 indicates suggested grass mixtures for use in grass waterways in B.C.

Table 5.7 Grass Seeding Mixtures Suitable for B.C.

Region	Grass Mixture	Conditions	Retardance
All regions except South coastal	Smooth Bromegrass Timothy Redtop	Not subject to long periods of standing water	B
South Coastal	Perennial Ryegrass Timothy Redtop	Not subject to long periods of standing water	C
All regions	reed canarygrass	standing water for long periods	A
All regions	redtop	standing water for long periods	C

The following points should be considered in selecting a grass seed mixture:

- germination rate
- hardiness for conditions present
- height of growth
- maintenance requirements
- attractiveness to wildlife such as waterfowl
- amount of seed bed preparation required

Table 5.8 Permissible Velocities for Channels Lined with Vegetation

Cover	Slope range (percent)	Permissible Velocity [a]	
		Erosion resistant soils m/sec	Easily eroded soils m/sec
Bermudagrass	0-5 [b]	2.5	1.8
	5-10	2.1	1.5
	over 10	1.8	1.2
Bahia Buffalograss Kentucky bluegrass Smooth brome Blue grama Tall fescue	[c]		
	0-5	2.1	1.5
	5-10	1.8	1.2
	over 10	1.5	0.9
Grass mixtures	0-5 [b]	1.5	1.2
Reed canarygrass	5-10	1.2	0.9
Lespedeza sericea Weeping Lovegrass Yellow bluestem Redtop Alfalfa Red fescue	[c]		
	0-5	1.1	0.75
Common lespedeza [d] Sudangrass	0-5 [e]	1.1	0.75

Notes:

a. Use velocities exceeding 1.5 meters per second only where good covers and proper maintenance can be obtained.

b. Do not use on slopes steeper than 10 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.

c. Do not use on slopes steeper than 5 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.

d. Annuals can be used on mild slopes or as temporary protection until permanent covers are established.

e. Use on slopes steeper than 5 percent is not recommended.

From Agricultural Engineers Handbook

Table 5.9 Classification of Vegetation Cover as to Degree of Retardance

Retardance	Cover	Condition
A		
	Reed canarygrass	Excellent stand, tall (900 mm)
	Yellow bluestem Ischaemum	Excellent stand, tall (900 mm)
	Smooth bromegrass	Good stand, mowed (300-375 mm)
	Bermudagrass	Good stand, tall (300 mm)
B		
	Native grass mixture (little bluestem, blue grama and other long and short midwest grasses)	Good stand, unmowed
	Tall fescue	Good stand, unmowed (450 mm)
	Lespedeza sericea	Good stand, not woody, tall (475 mm)
	Grass-legume mixture-Timothy, smooth bromegrass, or orchard grass	Good stand, uncut(500 mm)
	Reed canarygrass	Good stand, mowed (300-375 mm)
	Tall fescue, with bird's foot trefoi or lodino	Good stand, uncut (450 mm)
	Blue grama	Good stand, uncut (325 mm)
C		
	Bahia	Good stand, uncut (150-200 mm)
	Bermudagrass	Good stand, mowed (150 mm)
	Redtop	Good stand, headed (375-500 mm)
	Grass-legume mixture - summer Ordhard grass, redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (150-200 mm)
	Centipedegrass	Very dense cover (150 mm)
	Kentucky bluegrass	Good stand, headed (150-300 mm)
D		
	Bermudagrass	Good stand 65 mm
	Red fescue	Good stand, headed (300-450 mm)
	Buffalograss	Good stand, uncut (75-150 mm)
	Grass-legume mixture - fall, spring (Orchard grass redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (100-125 mm)
	Lespedeza sericea	After cutting to 50 mm height, Very good stand before cutting
E		
	Bermudagrass	Good stand cut to 37 mm height.
	Bermudagrass	Burned stubble

From U.S. Conservation Service

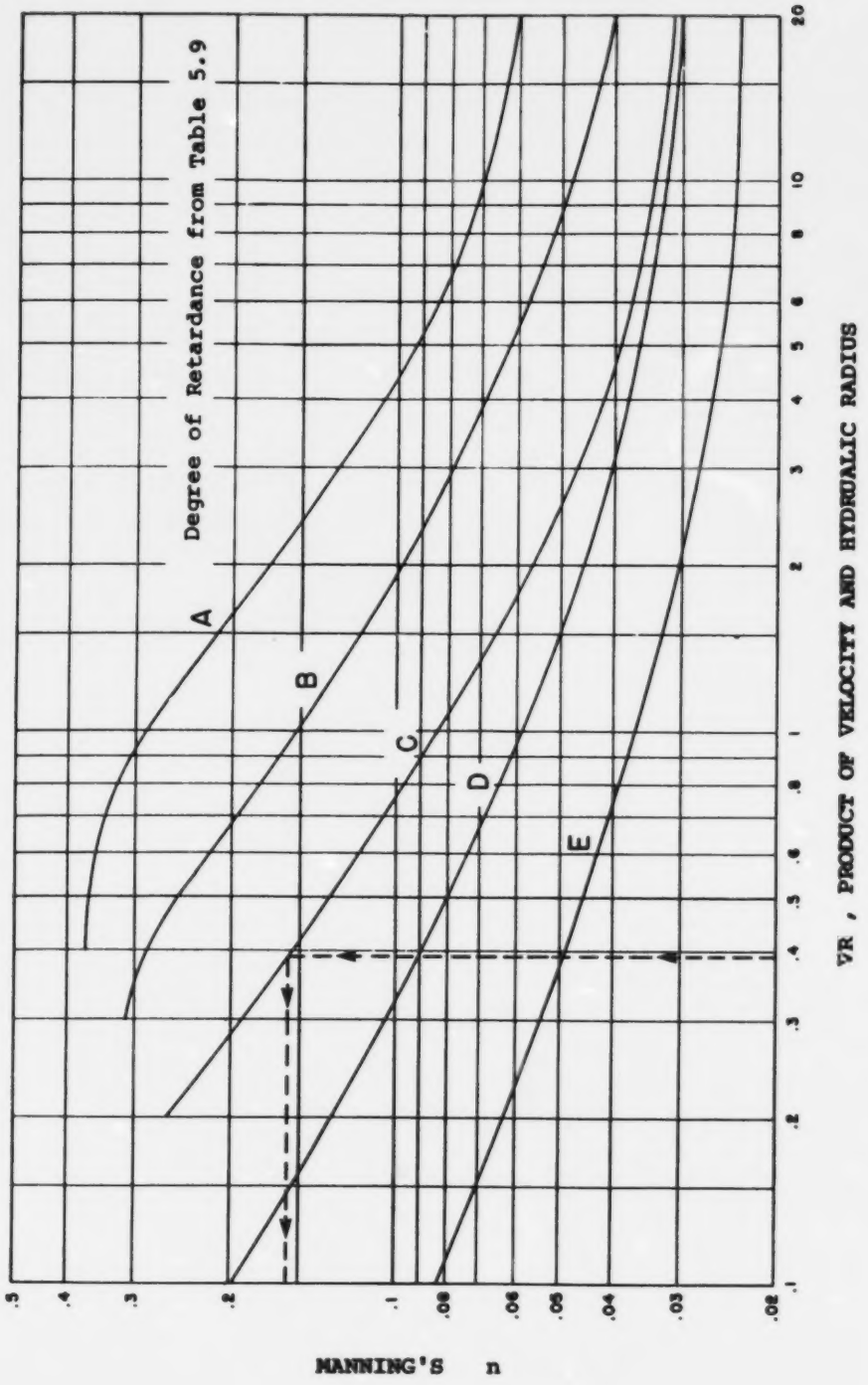


Figure 5.4 Manning's "n" Related to Velocity, Hydraulic Radius and Vegetal Retardance

From U.S. Soil Conservation Service

Example **Grassed Waterway Calculation**

A parabolic grassed waterway is being considered on a south coastal field with a 4 percent slope. The peak runoff has been calculated as 2.5 m^3/sec. The following parameters are given:

Vegetative cover	-	Perennial Ryegrass, Timothy, Redtop (Table 5.7)
Soil	-	Moderately Erodible
Vegetation Condition	-	Good stand 0.150 m - 0.20 m high
Slope (S)	-	0.04

What size of grassed waterway should be constructed?

From Table 5.6 and 5.8 Permissible velocity = 1.25 m/sec
From Table 5.9 Retardance C is selected

$Q = V \times A$ $\quad Q = 2.5\ m^3/sec$

$V = 1.25\ m/sec$

$A = \frac{Q}{V} = \frac{2.5\ m^3/sec}{1.25\ m/sec} = 2.0\ m^2$ minimum

To maintain the permissible velocity the minimum waterway section must be 2.0 m^2 in area.

From Table 5.5 cross sectional area of waterway $A = \frac{2Ty}{3}$

Wetted perimeter $P = T + \frac{8y^2}{3T}$

T = top width
y = design depth

$$\text{Therefore } \frac{2}{3} Ty > 2.0\ m^2$$

The solution for selecting the size of a grassed waterway is by trial and error. The waterway dimensions must be selected, and the capacity then calculated. If the capacity is not achieved, the dimensions must be adjusted and then reworked.

1st Trial

Select $T = 6m$

$y = 1.0m$

Therefore $A = \frac{2Ty}{3} = \frac{2(6)(1.0)}{3} = 4.0m^2$

$P = T + \frac{8y^2}{3T} = 6 + \frac{8(1.0)^2}{(3)(6)} = 6.4m$

Hydraulic Radius $R = \frac{A}{P} = \frac{4.0\ m^2}{6.4\ m} = 0.625m$

Estimate Velocity $V = \frac{Q}{A} = \frac{2.5\ m^3/sec}{4.0m^2} = 0.625\ m/sec$

$VR = 0.625 \times 0.625 = 0.39$

From Figure 5.4 For a VR of 0.39 and a vegetative resistance C, the roughness coefficient n = 0.155

$$Q = \frac{R^{2/3} \times S^{1/2} \times A}{n}$$

$$Q = \frac{(0.625)^{2/3} \times (0.04)^{1/2} \times 4.0}{(0.155)}$$

$$Q = 3.77\ m^3/sec$$

	T	y	A	P	R	V	VR	n	Q
1st Trial	6	1.0	4.0	6.4	0.625	0.625	0.39	0.155	3.77
2nd Trial	6	0.75	3.0	6.25	0.48	0.83	0.40	0.155	2.37
3rd Trial	6	0.80	3.2	6.23	0.51	0.78	0.40	0.155	2.64

Solution

A grassed parabolic waterway 6m wide and 0.80 m deep will be sufficient to carry 2.5 m^3/sec for the conditions noted in this example. The grassed waterway area exceeds the minimum waterway section to maintain permissible velocity. Graphical solutions for grassed waterway design can be obtained from the Engineering Field Manual, U.S. Soil Conservation Service.

VI SUBSURFACE DRAINAGE DESIGN

In subsurface drainage, perforated drains are installed below the soil surface to collect excess ground water and convey it to a gravity or pumped outlet. Surface drainage methods (e.g. open ditches and landforming) must often be used in conjunction with subsurface drainage systems.

The design of subsurface drainage systems is dependent upon the hydrologic characteristics of the soil, the required rate of discharge (climate and crop dependent), and the flow capacity of the drains.

Subsurface drainage is generally practiced on soils that are permeable enough for economical drain-spacings and productive enough to justify the investment.

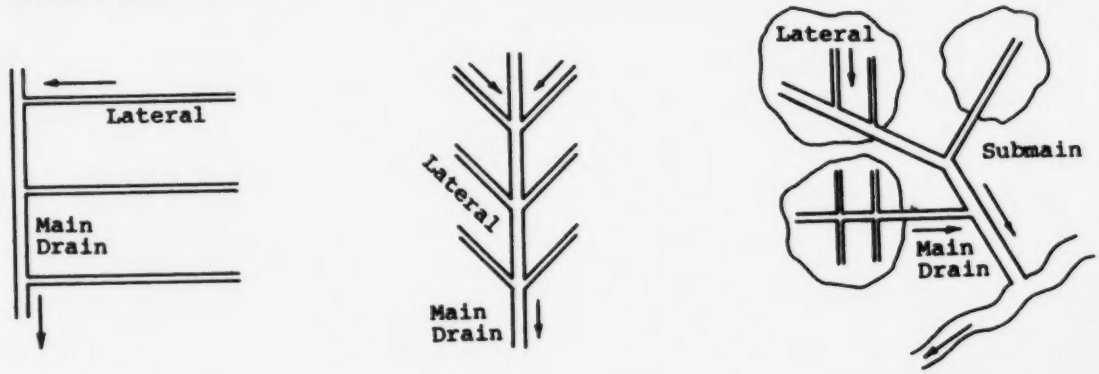
6.1 LAYOUT

A drainage system layout is determined mainly by topographic and soil features. There are three main layout patterns used in the design of subsurface drainage systems.

Parallel
A series of drains placed parallel to each other and usually spaced at regular intervals. This system is most commonly used and is employed wherever the topography is relatively flat.

Herringbone
This arrangement consists of one main line and a series of laterals which enter the main line at an angle. This system is most suited to drainage of relatively narrow and sloping depressions or valleys where the main line is placed in the lowest areas.

Random
Drains laid out in a manner to connect rleatively small, isolated, poorly drained areas in the most economic and effective way.



PARALLEL PATTERN HERRINGBONE PATTERN RANDOM PATTERN

Figure 6.1 Subsurface Drainage System Layouts

6.2 DRAINAGE COEFFICIENT

In subsurface drainage, the drainage coefficient is expressed as the depth of water (in mm) that a drainage system can remove from its entire drainage area in 24 hours.

When intercepting seepage on natural springs, the design rate of flow should be based on the actual rate of flow determined from field investigations.

The following procedure may be followed to determine the Drainage Coefficient for soils **in the Lower Fraser Valley.**

- Determine the type of crop to be grown and establish the number of days the crop can tolerate a waterlogged soil. Table 4.5 can be used as a guide.
- Determine the allowable water table depth that the crop and/or soil management can tolerate for not more than the number of days found above. Table 2.1 can also be used as a guide. Often trafficability requirements will dictate an allowable minimum water table depth of 0.5 m.
- Determine the cultivation season for the specific area the crop is located.
- With information from the three points above determine the appropirate Drainage Coefficient from Table 6.1

Table 6.1 Drainage Coefficient for the Lower Fraser Valley (mm/day)
(Based on 30 years weather data)

Crop Tolerance[a]	Region A[b]		Region B[c]	
	Water Table Depth Below Soil Surface			
	0.3m[d]	0.5m[e]	0.3 m	0.5 m
High (up to 4 days)	16.0	19.0	9.5	11.5
Medium (up to 3 days)	18.5	21.0	11.0	12.5
Low (1-2 days)	22.0	22.5	13.0	13.5

a. Number of days that a crop can tolerate waterloggged soil without suffering significant decrease in growth and production.

b. Areas whose cultivation season must begin in March.

c. Areas whose cultivation season begins in April (after March).

d. When the allowable water table depth is 0.3 m or less for not more than the crop tolerance level (indicated number of successive days).

e. When the allowable water table depth is 0.5 m or less for not more than the crop tolerance level indicated.

Until further data is generated for the remainder of the province, Table 6.2 can be used to determine drainage coefficients.

Table 6.2 Drainage Coefficients for Selected Regions of B.C.

Region	Drainage Coefficient mm/day
Gulf Islands	12 mm/day
Vancouver Island	12 mm/day
North Okanagan Region	12 mm/day
Creston Region	9 mm/day

If blind inlets are used on a subsurface drainage system the drainage coefficient should be increased. Careful evaluation is then required to determine the drainage system capacity. Surface runoff values should be calculated to determine an appropriate drainage coefficient.

Example Drainage Coefficient Selection

A farmer in the Abbotsford area has 20 ha. of loam soil in pasture that needs drainage. He starts cultivating at the beginning of April. Calculate the drainage coefficient.

- From Table 4.5 the Crop Tolerance to flooding is 3 days.
- From Table 2.1 the allowable water table depth is 0.5 m.
- The cultivation season is known to be after the end of March.
- From Table 6.1 the Drainage Coefficient is 12.5 mm/day.

6.3 DRAIN DEPTH

Drain depths in the 0.9 to 1.5 m range are recommended. A general depth of 1.2m is often used. This may be reduced to 0.8 m under the following conditions:

- where a slowly permeable soil exists
- where hardpan, rocks, stone, sand or dense soil prohibit greater depth
- where the outlet depth of the drain is limited
- where depressional or impounded areas exist

The minimum cover to protect a subsurface drain from breakage by farm machinery is 0.6 m for drains up to 150 mm in diameter and 0.8 m for drains from 150 mm up to 450 mm in diameter.

If it is impossible or uneconomical to secure the minimum cover specified above due to culverts, road ditches, or other reasons, high-strength non-performated pipe should be used. The deeper the drain tile, the more effective the drainage system becomes.

The following two soil conditions require special attention regarding drain depths and installation:

Hardpan

Hardpan is an impermeable layer or formation in the soil which restricts downward movement of water. The most frequently encountered types of hardpan are glacial marine and glacial till. Where hardpan occurs at shallow depth (1 m or less) drains may be placed 0.15 m into the hardpan but never less than 0.65 m deep. Blinding with porous material such as drain rock, pea gravel, shavings or equivalent material is required for these situations. Adjustments must be made to the drain spacing to compensate for drain depth restrictions.

Porous blinding material must be applied at least to the hardpan level. Drains crossing depressions which are frequently encountered in hardpan soils should be blinded and backfilled to provide a blind surface inlet.

Organic Soil

Organic soil, also known as peat or muck depending on the state of decomposition, contains 30 percent or more organic material. Shallow organic soils (0.6 m or less) generally do not require special treatment. In cases where the organic material reaches a depth of 0.6 m to 1.0 m some water level control should be attempted. Unnecessary lowering of the water table and an accompanying increase in decomposition of organic soil will cause land settling. Particular caution must be used where floating or semi-floating bogs or meadows are concerned since "settling" may be so severe that normal lowering of the water table is ineffective.

Deep organic soils in which the organic material exceeds a depth of 1 m require water table control and special materials such as continuous plastic drains, plank drains or equivalent material which cannot shift or become misaligned due to uneven settling. A minimum drain depth of 1.2 m must be used to offset land settling. Shallow drains quickly lose their effectiveness as land settlement may subject drains to damage from field operations.

6.4 DRAIN SPACING

When a parallel lateral system is used, the spacing between laterals should be based on soil type, drain depths, crops to be grown, trafficability and drainage coefficient chosen.

Generally, the narrower the spacing is, the better the control of water table in the ground. However, selection of the most economic system calls for determination of the maximum drain spacing which can be tolerated by crops to be grown.

The Hooghoudt equation may be used to compute the spacing between lateral drains.

Luthin (1978) states that there are as many as 160 drainage theories available. For the half-dozen drainage depth and spacing equations which are frequently used, the difference in spacings calculated for a particular field is seldom more than 10% of the spacing. Hooghoudt's equation based on steady state seepage through saturated soil to either drainpipes or ditches is widely used in Canada. The equation for homogeneous soil can be expressed as:

$$S^2 = \frac{4K(2d_e h + h^2)}{R}$$

and for a two layered soil as:

$$S^2 = \frac{(8K_b d_e h + 4K_a h^2)}{R}$$

where S = Spacing between drain lateral, m

h = water table height above the drains at mid-spacing, m

* R = drainage coefficient (drainage rate), m/day

d_e = equivalent depth of impermeable layer below drain center, m

K_a, K_b = hydraulic conductivities of soil layers above and below the drain, respectively m/day. When $K_a = K_b$ the soil is considered to be homogeneous.

* Drainage coefficient units are normally in mm/day. For the Hooghoudt equation the units used are m/day. Make sure the units used in the equation are correct.

Figure 6.2 Defines the symbols used in the above equations.

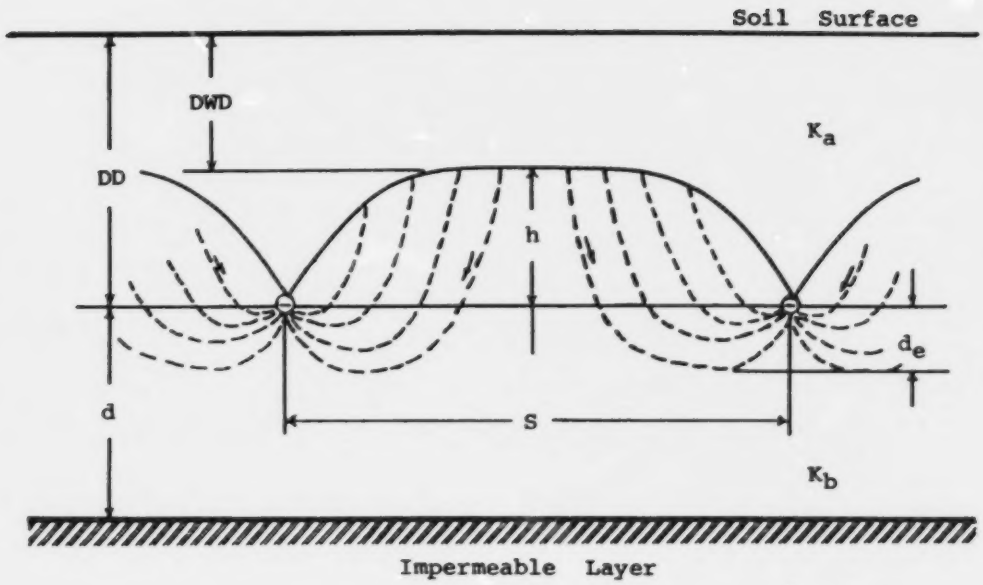


Figure 6.2 Definition of Parameters for Subsurface Drainage Systems

The following procedures may be followed for the use of this method:

1. Select an appropriate drainage coefficient, R.

2. From the knowledge of crop information, a value of h is determined. As can be seen in Figure 6.1, h = DD - DWD where DD is the drain depth (see section 6.3 in this guide) and DWD is the desirable water table depth from the soil surface. It appears that 0.3 - 0.5 m is a widely used range for DWD.

3. Determine the saturated hydraulic conductivities of the soil above and below the drain, respectively. If $K_a = K_b$, the soil is said to be homogeneous with respect to hydraulic conductivity. See Appendix A for method and procedures for hydraulic conductivity measurements.

4. By using Hooghoudt's equation, calculate S from an adequate equivalent depth. (d_e = 1m may be used as an initial estimate) Figures 6.3 - 6.5 can be used to check the estimated d_e. A trial and error approach is required to select a d_e which matches the d_e found in Figures 6.3 - 6.5 for the drain spacing S calculated.

5. A drain diameter must also be selected at this stage. If the drain size selected is not capable of handling the capacity determined in Section 6.5, the drain spacing should be recalculated for the revised drain size. Usually a 100 mm drain is selected first, as only special cases and mainlines will warrant larger diameters.

Example **Drain Spacing Selection**

A farmer in Abbotsford has a 20 ha farm in pasture on a loam soil. The land requires drainage. In section 6.2 the drainage coefficient (R) was calculated to be 12.5 mm/day.

A soil survey indicates that the water table depth is 1.5 m with an impermeable layer encountered at 5 m. Hydraulic conductivity measurements indicate a value of 0.25 m/day. Determine the drain depth and spacing.

From Table 2.1 - The allowable water table depth = 0.50 m

Using Figure 6.2 DWD = 0.50 m

From Section 6.3 - A drain tile depth of 1.2 m is selected.
DD = 1.2 m

Using Figure 6.2 - h = DD - DWD
= 1.2 m - 0.5 m = 0.7 m

From soil surveys the saturated hydraulic conductivities of the soil above and below the tile was found to be the same.

$$K_a = K_b = 0.25 \text{ m/day}$$

For an impermeable layer depth of d = 5m - DD = 5m -1.2m = 3.8 m an initial estimate of an equivalent depth of d_e = 1.0 m is selected.

Since this is a homogenous condition the drain spacing can be calculated from:

$$S^2 = \frac{4K(2d_e h + h^2)}{R}$$

where $K = 0.25$ m/day

$h = 0.7$ m

$d_e = 1.0$ m

$R = 12.5$ mm/day = 0.0125 m/day

$$S^2 = \frac{4\ (0.25)\ (2(1.0)(0.7) + (0.7)^2)}{0.0125}$$

$S = 12.3$ m

Select a 100 mm drain tile size

From Figure 6.4 for S = 12.3 m and d = 3.8 m
the equivalent depth, d_e = 1.1 m

Recalculate S using de = 1.1 m

$$S^2 = \frac{4(0.25)\ (2\ (1.1)(0.7) + (0.7)^2)}{0.0125}$$

$$S = 12.7 \text{ m}$$

From Figure 6.4 for S = 12.7 m and d = 3.8 m, the equivalent
depth de = 1.15

A trial and error approach must be used to solve for de and S. In this example a drain spacing of 13.0 m is selected as de = 1.15 m is close enough to the value of 1.1 m used to calculate the drain spacing.

Table 4.3 can be used to check if the drain spacing calculated matches the approximate drain spacing range for a given soil type. In this case the system is overdesigned to maintain a water table depth of 0.5 m. The drain spacing calculated is therefore slightly lower than the range of spacings shown in Table 4.3.

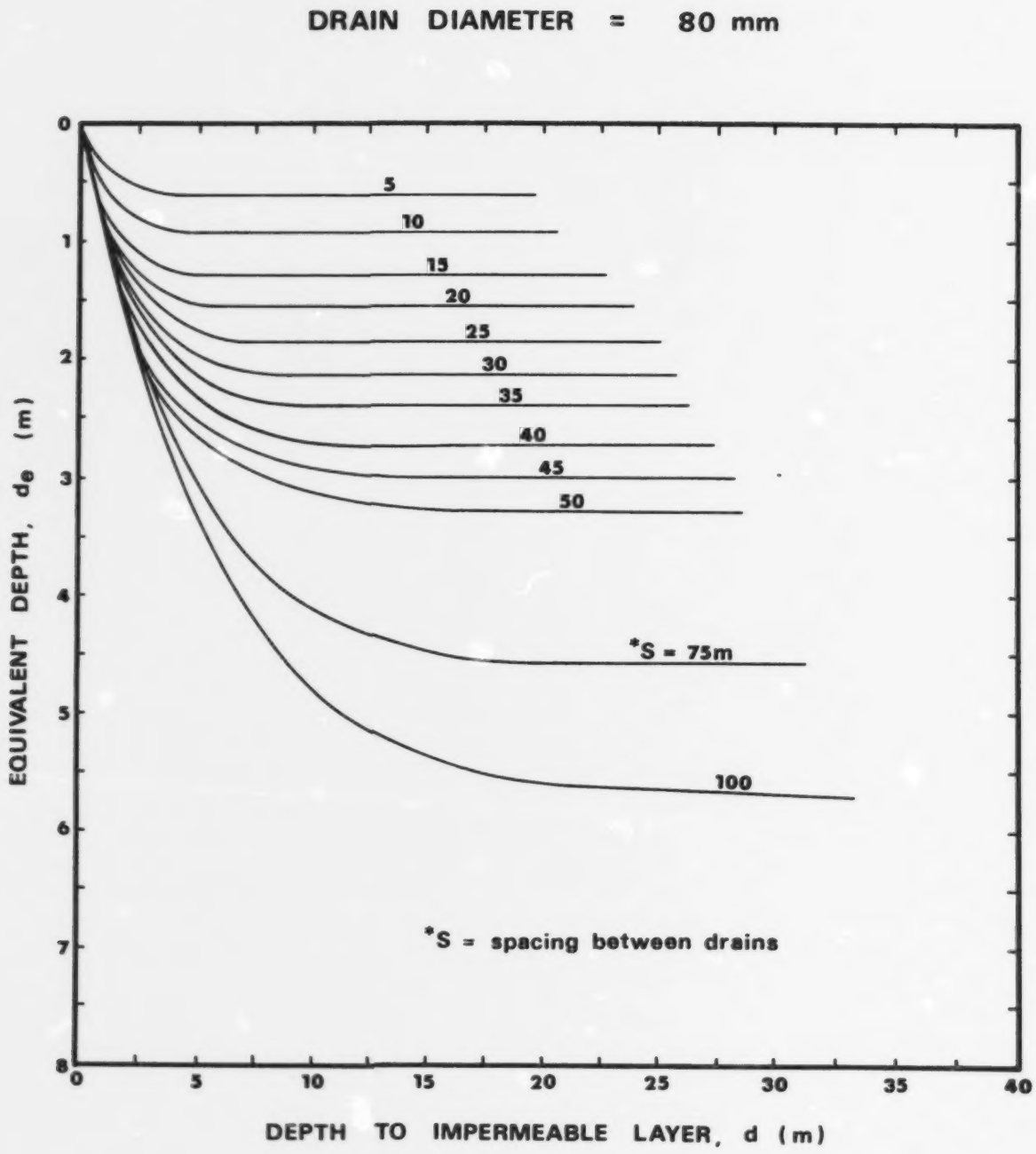


Figure 6.3 Relationship Between d and d_e.

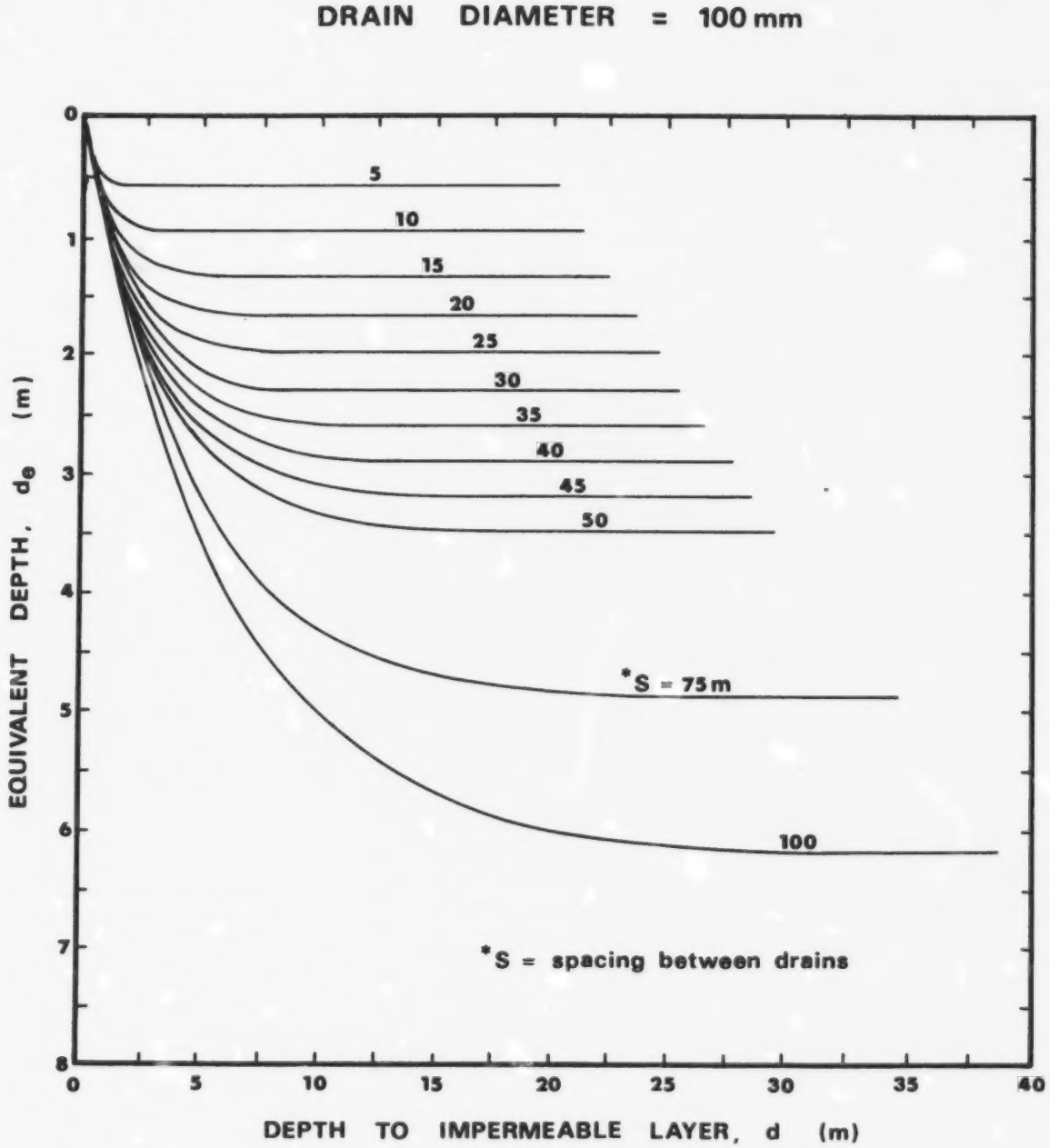


Figure 6.4 Relationship Between d and d_e.

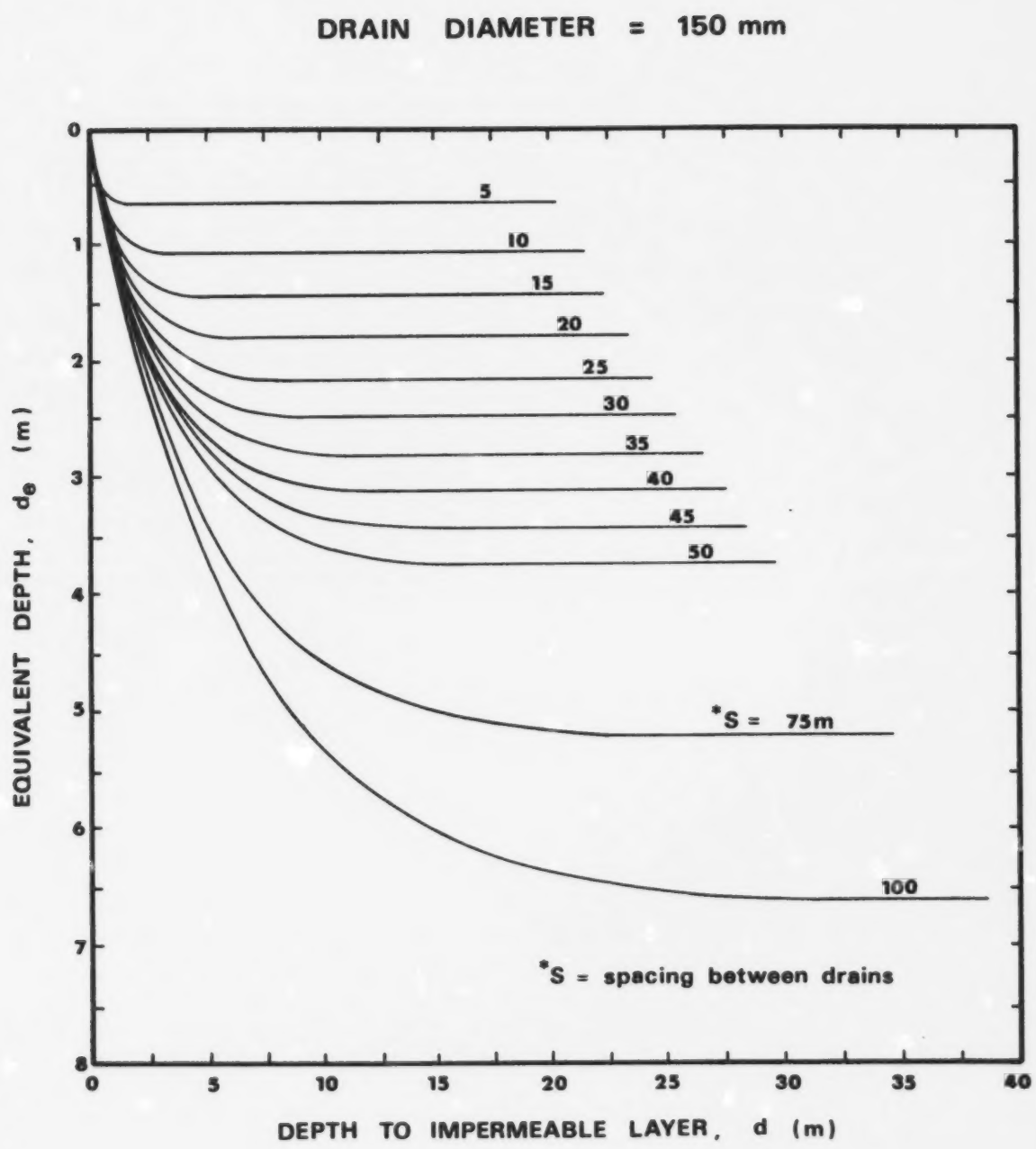


Figure 6.5 Relationship Between d and d_e.

6.5 DRAIN PARAMETERS

Drain Size Selection

The diameter of a drainage pipe depends upon the volume of water to be carried, the grade of the drain and internal roughness of the pipe. The volume of water depends upon the soil hydraulic conductivity, the spacing of the drains, and the area drained. The proper size of drain can be selected directly from Figure 6.6.

Example 1 A drain on a grade of 0.5% used as a main collector for 5 hectares of land at a drainage coefficient of 12 mm/day will require a clay tile or corrugated plastic tube of 150 mm diameter.

Grade

Subsurface drains with very little or reverse grade tend to fill with sediments. If the grades of the drains are too steep, excessive velocities may occur and result in erosion hazard to the soils surrounding the drains. Maximum and minimum grades given in Table 6.3 are recommended.

Table 6.3 Grade of Drain

Minimum (%)		*Maximum (%)
Diameter of Drain (mm)		Laterals - subjected to pressure flow must not exceed 2%
80	0.20%	Mainlines - under Full Flow
100	0.10%	
150	0.05%	Sandy Soil - 1% Silt or Loam - 2% Clay - 6%

*When grades exceed those specified in Table 6.3, continuous rigid or nonperforated pipe must be used.

Maximum grade of main drains should not produce velocities exceeding the following:

Soil Texture	Velocity m/sec
Sand - sandy loam	1.0
Silt - silt loam	1.5
Silty clay loam	1.8
Clay and clay loam	2.0
Coarse sand and gravel	2.5

Drains should be sized to ensure velocities remain below the above values for soil conditions present.

Capacity

Figure 6.6 may also be used to determine the required drain capacity based on the selected drainage coefficient.

Example 2 Determine the drain capacity of a drain on a 0.1% grade 500 m long and a 15 m spacing. The drainage coefficient is 12 mm/day.

Area drained = L x S
= 500 m x 15 m = 7500 m^2
= 0.75 ha

Figure 6.6 shows that the drain capacity of 1.0 litres per second is required.

If the drain is to be used to intercept seepage or spring water, adequate field investigations must be made to determine the amount of water that must be taken care of.

Figure 6.6 can also be used to select the drain size. In this example a 100 mm drain diameter is selected.

Length of Drain Lines

Figure 6.6 can be used to determine the maximum allowable length of a drain for a given set of design parameters. Example 3 on Figure 6.6 illustrates this feature.

Example 3

Grade = 0.1%
Drainage Coefficient = 12 mm/day
Drain spacing = 15 m

If 100 mm diameter corrugated plastic tubing is used, **the maximum length of the single drain line or the total of a series of lateral lines must not exceed 625 meters.**

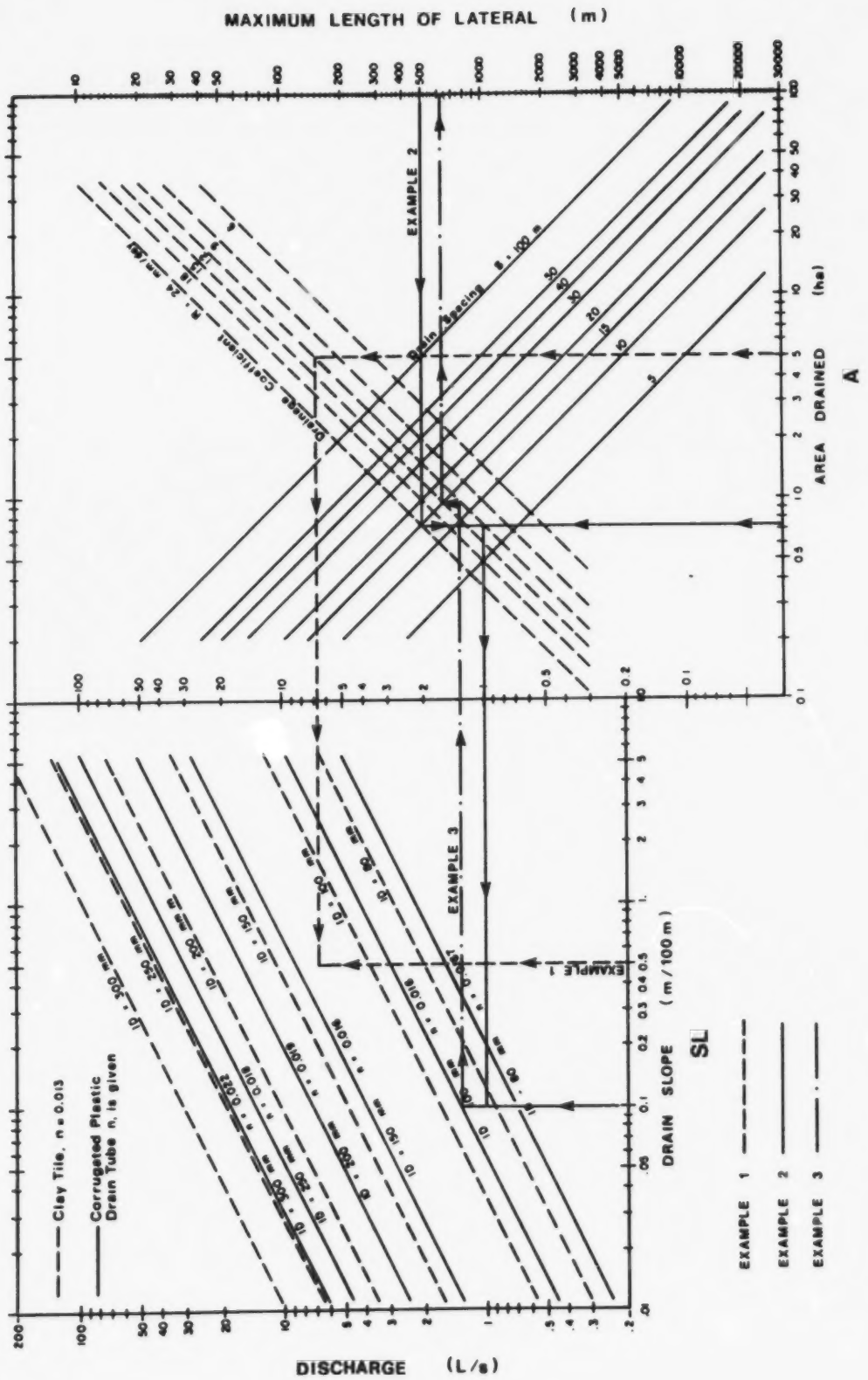


Figure 6.6 Multiple Correlation Graph

6.6 DRAINAGE PLAN PARAMETERS

A drainage plan is essential for the installation of a drainage system and equally important for future maintenance purposes. In producing a drainage plan, the following standards are recommended: (Figure 6.8)

- Use a plan scale of 1:1000 (i.e 1 mm to 1000 mm, or 1mm to 1m) or other suitable scale based on data obtained in the field.

- Show bench marks and give their descriptions and locations.

- Use 0.5 m contour lines or 0.25 m contour lines on very level fields and include numerous spot elevations for the field and ditches.

- Locate ditches, drains, culverts, miscellaneous structures and appropriate landmarks on the drawing.

- Show the invert elevation and size of culverts and other structures which could restrict water movement.

- Note the sizes, grades, lengths and control elevations of drains plus the locations of changing grades and sizes of drains.

- Provide various cross-sections and complete profiles of new and existing outlet ditches.

- Show the maximum, minimum and normal water levels of the outlets (i.e ditch water level fluctuations).

- Provide a clear legend of all the symbols used.

- Include a north arrow and suitable geographic landmarks (i.e major roads, rivers, and all utility lines.

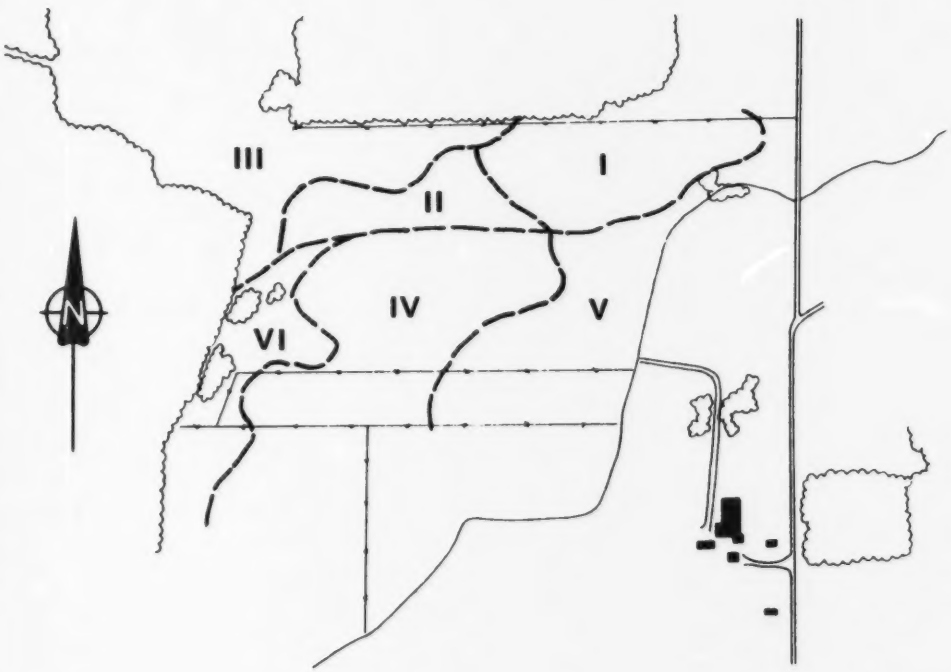
- Supply a table of the total length of drains and their sizes.

- Provide special notes and recommendations (if any) for the system designed.

- Provide a map of the soil boundaries with a description and recommendations. A sample soils map and drainage plan are shown in Figures 6.7 and 6.8.

- Pump location, size and capacity, including power location.

SOIL MAP



SOIL TYPE	DEPTH cm		DESCRIPTION
I	0 -	70	Humified sediment
	70 -	230+	Mesic to wood deb
II	0 -	10	Humified
	10 -	37	Sandy cl quasi-cer
	37 -	70	Fine san
	70 -	105+	Stoney,
III			Not surv
IV	0 -	20	Loam - s
	20 -	50	Concreti
V	0 -	30	Loam to
	30 -	50	Silt loa
	50 -	150+	Clay, fi scattere
VI			Similar

SOIL TYPE	DRAIN SPACING m	DRAIN DEPTH m	R
I	10	1.0	
II	15	0.80	
III	No drains required.		
IV	No drains required.		
V	15	0.80	
VI	-	-	

NOTE: Water accumulatio conditions and de Improvement of th will provide basi is related to poo the soil, through drainage system i for special Soil

Water problems of should be alleviat However, here als depend on soil ma

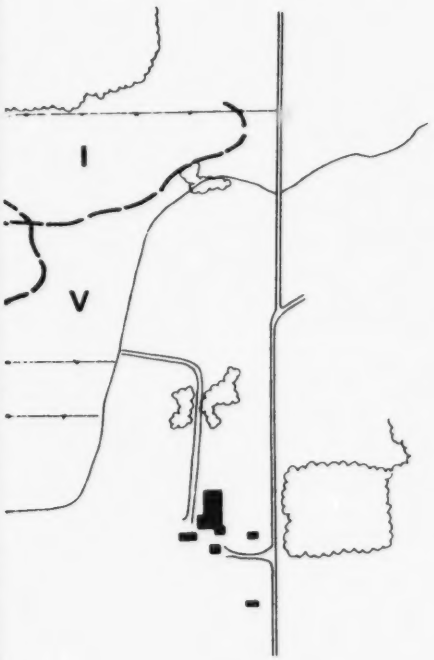
SCALE 1:8,900

LEGEND: SOIL BOUNDARY, FENCE, ROAD, DITCH, UNCLEARED LAND, BUILDING

DRAINAGE SURVEY REP

PROVINCE OF BRITI
SOILS BRA
MINISTRY OF AGRICULT

MAP



DESCRIPTION

SOIL TYPE	DEPTH cm	DESCRIPTION
I	0 - 70	Humified organic material interstratified with tl sediment (silt loam - clay loam).
	70 - 230+	Mesic to fibric organic material becoming mesic v wood debris.
II	0 - 10	Humified organic material.
	10 - 37	Sandy clay, reddish brown, abundant concretions, quasi-cemented.
	37 - 70	Fine sandy clay, abundant concretions distinct m
	70 - 105+	Stoney, gravelly, sandy clay very firm, strongly
III		Not surveyed. Mostly well drained sands and gra
IV	0 - 20	Loam - sandy loam, scattered gravels, concretiona
	20 - 50	Concretionary stoney sandy clay, very firm compac
V	0 - 30	Loam to fine sandy loam, granular.
	30 - 50	Silt loam to silty clay loam, firm and compact, c
	50 - 150+	Clay, firm to very firm, strongly mottled, modera scattered stones.
VI		Similar to type IV soil except for higher degree

RECOMMENDATIONS

SOIL TYPE	DRAIN SPACING m	DRAIN DEPTH m	REMARKS
I	10	1.0	Provide controls to prevent excessive dec
II	15	0.80	
III	No drains required.		
IV	No drains required.		See note.
V	15	0.80	See note.
VI	-	-	Intercept runoff along N. Boundary (see r

NOTE: Water accumulation in the soil occurs mainly due to a comb conditions and dense, impermeable subsoil at shallow depth Improvement of the creek level and construction of the dra will provide basic discharge and conveyance facilities. H is related to poor structural conditions of the soil itsel the soil, through subsoiling and other cultural practices, drainage system is limited. Recognition of the limitation for special Soil Management Inputs is essential.

Water problems of Soil VI and II are primarily related to should be alleviated with an appropriated interceptor alon However, here also some of the problems are related to adv depend on soil management for improvement.

SCALE 1:8,900

LEGEND: SOIL BOUNDARY, FENCE, ROAD, DITCH, UNCLEARED LAND, BUILDING

DRAINAGE SURVEY REPORT

SURVEY: M. Driehuyzen & D. Pe

REPORT

PROVINCE OF BRITISH COLUMBIA
SOILS BRANCH
MINISTRY OF AGRICULTURE AND FOOD

PHOTO NO. 7761:258

REPORT NO. 82-08-13

DESCRIPTION

DEPTH cm	DESCRIPTION
0 - 70	Humified organic material interstratified with thin lenses of mineral sediment (silt loam - clay loam).
'0 - 230+	Mesic to fibric organic material becoming mesic with depth, scattered wood debris.
0 - 10	Humified organic material.
0 - 37	Sandy clay, reddish brown, abundant concretions, in places weak or quasi-cemented.
7 - 70	Fine sandy clay, abundant concretions distinct mottling and gleying.
0 - 105+	Stoney, gravelly, sandy clay very firm, strongly gleyed.
	Not surveyed. Mostly well drained sands and gravelly materials.
) - 20	Loam - sandy loam, scattered gravels, concretionary, moderately firm.
) - 50	Concretionary stoney sandy clay, very firm compact.
) - 30	Loam to fine sandy loam, granular.
) - 50	Silt loam to silty clay loam, firm and compact, occasionally weakly cemented.
) - 150+	Clay, firm to very firm, strongly mottled, moderately gleyed. Occasional, scattered stones.
	Similar to type IV soil except for higher degree of poor drainage.

RECOMMENDATIONS

MIN CING %	DRAIN DEPTH m	REMARKS
	1.0	Provide controls to prevent excessive decomposition.
	0.80	
drains quired.		
drains quired.		See note.
	0.80	See note.
	-	Intercept runoff along N. Boundary (see note).

ıter accumulation in the soil occurs mainly due to a combination of poor outlet nditions and dense, impermeable subsoil at shallow depth.
provement of the creek level and construction of the drains in adjacent low areas ll provide basic discharge and conveyance facilities. However, much of the problem related to poor structural conditions of the soil itself. Without improvement to e soil, through subsoiling and other cultural practices, the effectiveness of a ainage system is limited. Recognition of the limitations of drainage and the need r special Soil Management Inputs is essential.

ter problems of Soil VI and II are primarily related to seepage from the north and ould be alleviated with an appropriated interceptor along the north boundary. wever, here also some of the problems are related to adverse soil conditions which pend on soil management for improvement.

AGE SURVEY REPORT

PROVINCE OF BRITISH COLUMBIA
SOILS BRANCH
MINISTRY OF [illegible]

SURVEY: M. Driehuyzen & D. Pedersen
REPORT

PHOTO NO. 7761:258

REPORT NO. 82-08-13

NAME & ADDRESS

EXAMPLE DRAINAGE
PLAN NO. 100.448

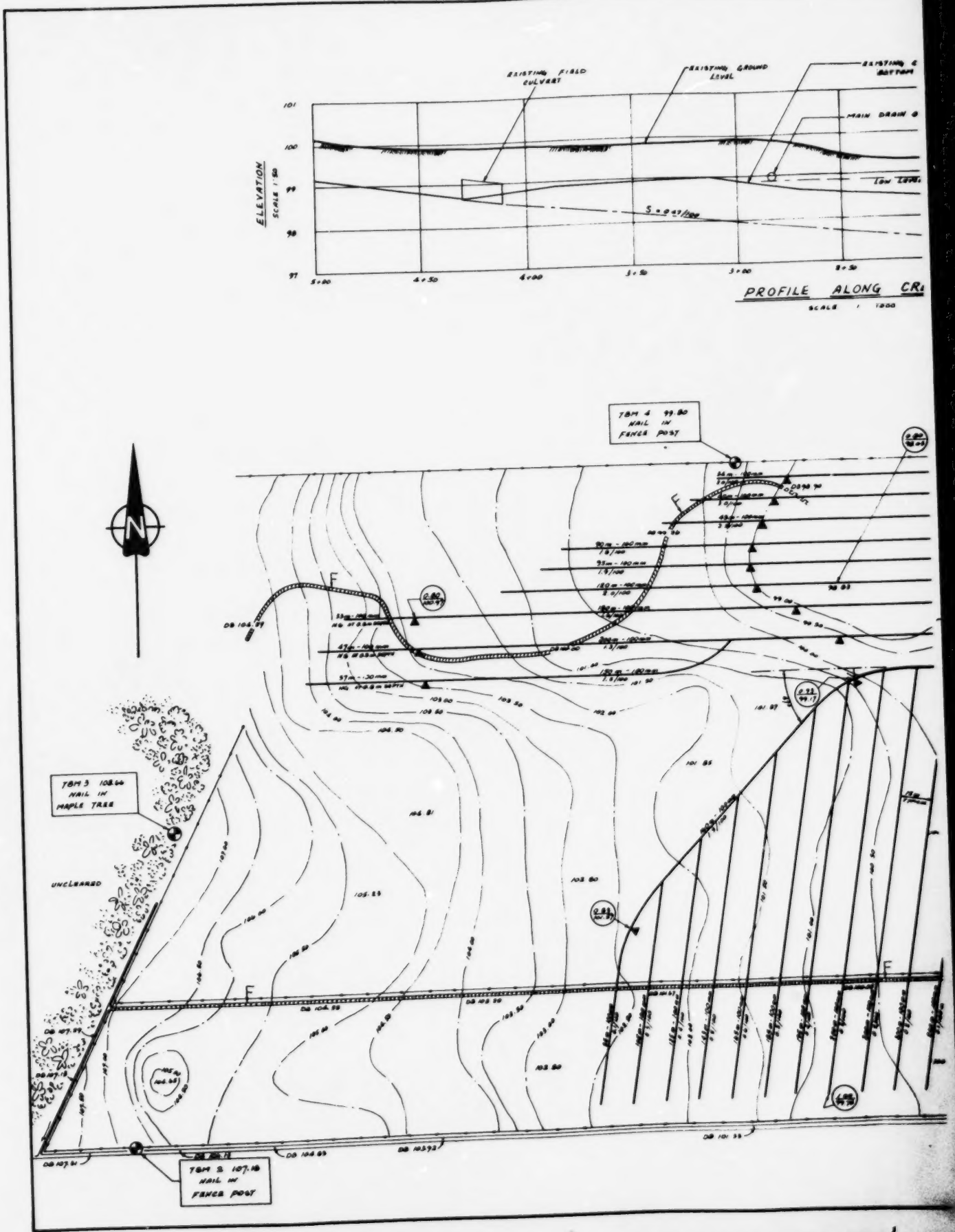
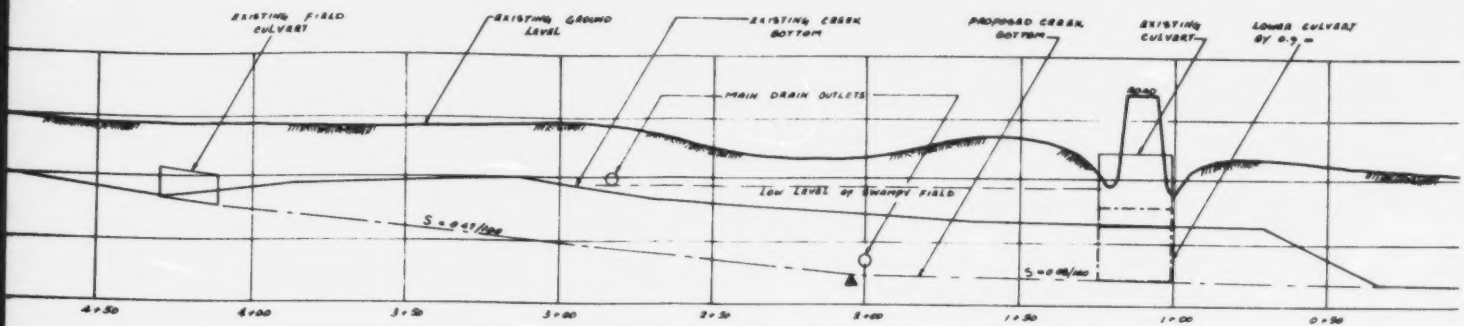
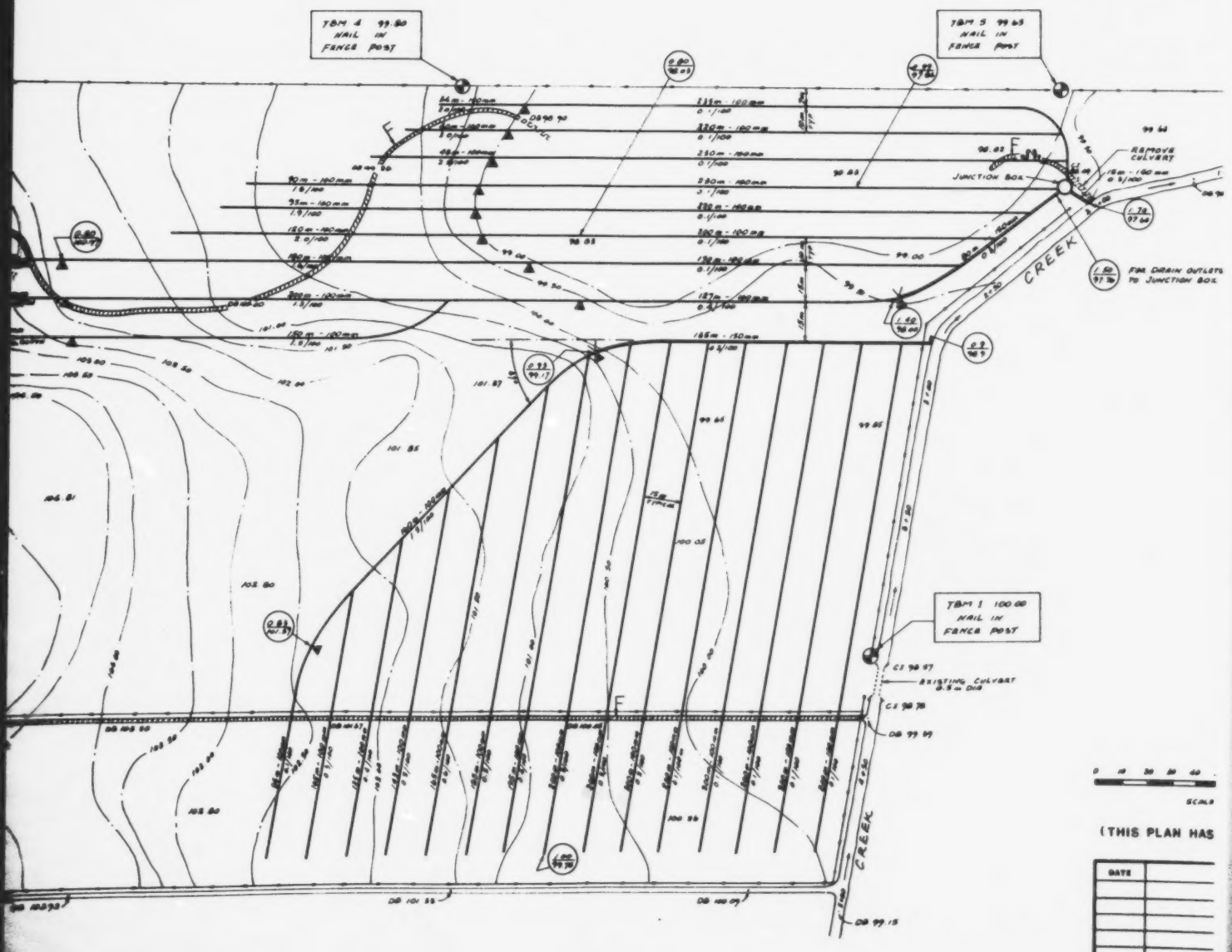


Figure 6.9 Sample Drainage Plan



PROFILE ALONG CREEK

SCALE : 1000



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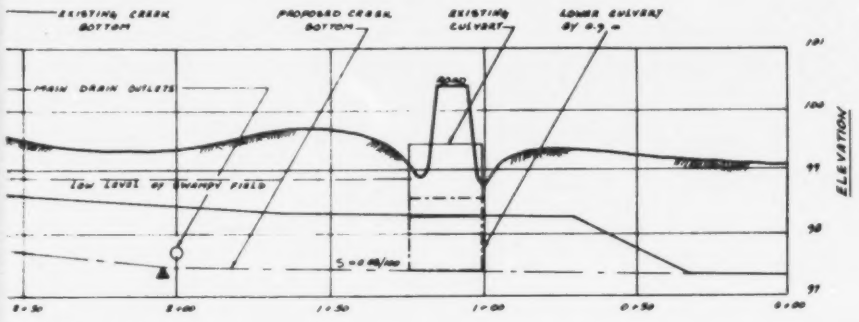
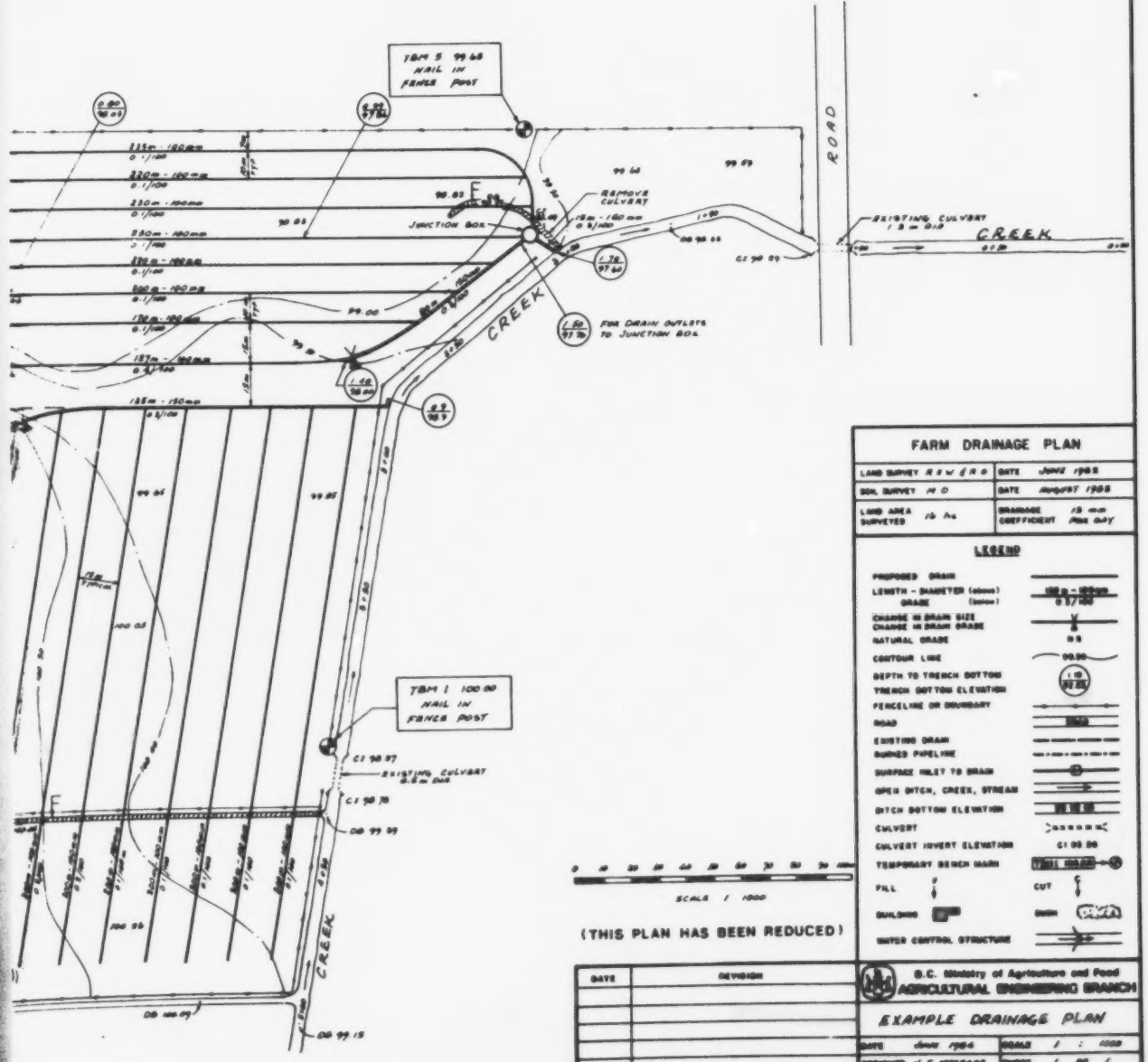
DATE	



ALONG CREEK

1 : 1000



(THIS PLAN HAS BEEN REDUCED)

FARM DRAINAGE PLAN

LAND SURVEY R O W & R O	DATE June 1983
SOIL SURVEY M O	DATE August 1983
LAND AREA SURVEYED 15 ha	DRAINAGE COEFFICIENT 13 mm/day

LEGEND

PROPOSED DRAIN
LENGTH - DIAMETER (above) GRADE (below) 180 m - 150 mm 0.1/100
CHANGE IN DRAIN SIZE
CHANGE IN DRAIN GRADE
NATURAL GRADE 0.5
CONTOUR LINE 98.00
DEPTH TO TRENCH BOTTOM 1.8 m
TRENCH BOTTOM ELEVATION 97.76
FENCELINE OR BOUNDARY
ROAD
EXISTING DRAIN
BURIED PIPELINE
SURFACE INLET TO DRAIN
OPEN DITCH, CREEK, STREAM
DITCH BOTTOM ELEVATION 98.46
CULVERT
CULVERT INVERT ELEVATION C1 98.96
TEMPORARY BENCH MARK TBM 1 100.00
FILL
CUT
BUILDING
WATER CONTROL STRUCTURE

DATE	REVISION

B.C. Ministry of Agriculture and Food
AGRICULTURAL ENGINEERING BRANCH

EXAMPLE DRAINAGE PLAN

DATE June 1984	SCALE 1 : 1000
DESIGNED J. F. MAYBANK	SHEET 1 OF 1
DRAWN L. SEAGER	PLAN No. 100.448
CHECKED	

6.6 ENVELOPES AND FILTER MATERIALS

Envelopes for drains are permeable materials placed around the drains for the purposes of improving flow conditions in the area immediately surrounding the drain, and for improving bedding conditions.

Filters for drains are permeable materials placed around the drains for the purpose of preventing fine-grained materials in the surrounding soils from being carried into the drain by groundwater.

In past years, clay tile, and corrugated drainage pipe were installed with a covering layer of organic material. Common materials used were wood chips, sawdust, and straw. The handling of these materials is often laborious. **The use of wood waste materials such as chip and sawdust is not recommended due to possible environmental contaminants from "toxic leachates" produced by them.**

Corrugated plastic drain pipe is now available with a factory prewrapped synthetic envelope material. Since most groundwater enters the drain from below, the advantage of a completely wrapped pipe, especially in soils with poor stability is obvious.

In certain areas a very coarse sand to fine gravel, ranging in particle size from 0.5 to 20 mm, provides an effective envelope. The cost for this envelope material may, however, be high.

The proper selection of pipe and envelope materials does not always guarantee that a drain will function properly. A decisive factor appears to be favourable soil moisture conditions at the time of installation. Backfilling an excavated trench during periods of high watertable can be particularly detrimental. If the soil structure in the vicinity of the drain deteriorates through smearing, kneading, compaction, or sedimentation, water flow into the drain will be impaired. If possible, install drains under relatively dry field conditions when the water table is below drain depth. If the drain is installed in a soil with a high water table, the envelope material will often plug immediately when installed in a sand or silt soil.

Figure 6.9 indicates methods of installing envelope materials.

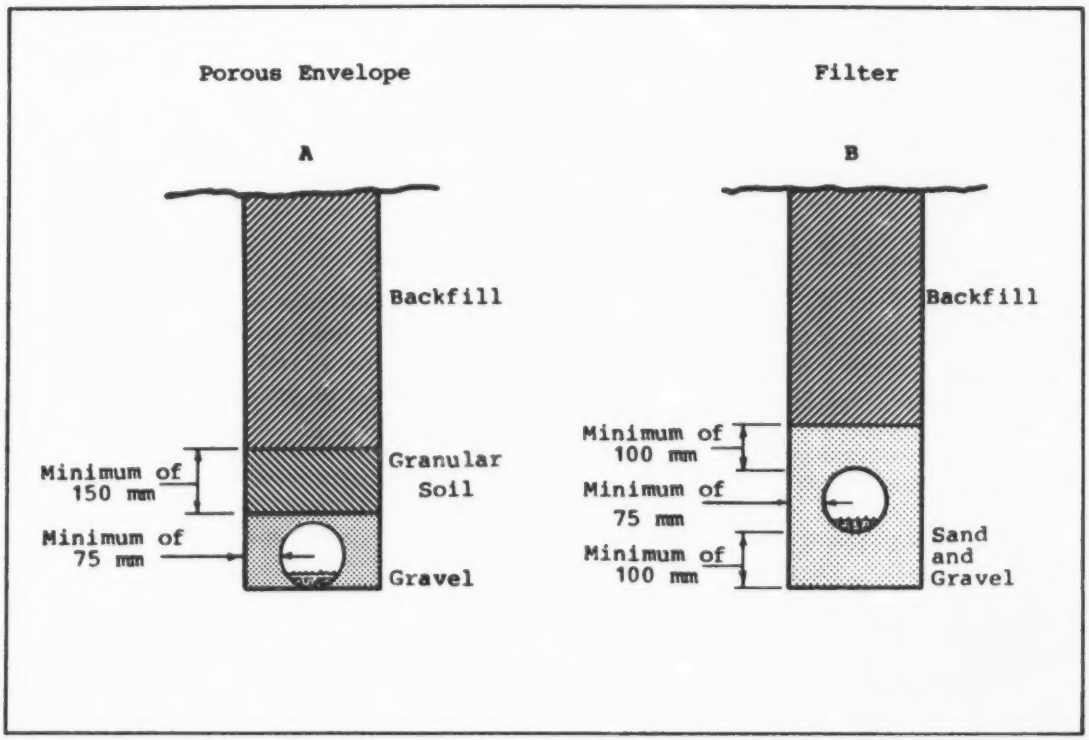
Flow sand is a condition in which sand grains are displaced or eroded by the flow of water. Under flow sand conditions, water flow will carry sand into unprotected drains and either deposit it in the drains or discharge it into the outlet. Since much of the water enters a drain from below, erosion of sand below the drain takes place resulting in the formation of "sink holes" under the drain.

Suitable filters may be used to restrict fine particles of silt and sand from entering the drains. In addition a properly designed envelope stabilizes the soil around the drain and allows free entry of water. Filters should be fairly well-graded from coarsest to finest material.

Table 6.4 provides information on when envelopes or filters are needed.

Table 6.4 Drain Filter and Envelope Recommendations

Soil Texture	Envelope or Filter Recommendations	Degree of Urgency
Gravel	None	None
Gravelly Coarse Sand	None	None
Very Coarse Sand	None	None
Gravelly Fine Sand	Filter	Moderate
Medium Sand	Filter	High
Fine Sand	Filter	Very High
Loamy Sand	Filter	High
Sandy Loam	None	None
Loam	None	None
Silt Loam	Porous Envelope	Low
Silty Clay Loam	Porous Envelope	Moderate
Sandy Clay	Porous Envelope	Moderate
Silty Clay	Porous Envelope	High
Clay	Porous Envelope	High
Peat	None	None
Muck	None	None



Drawing A - Envelope material is placed above and around the drain to improve flow conditions into the drain.

Drawing B - Filter material is placed completely around the drain to prevent fine-drained material from entering the drain.

Figure 6.9 Methods of Placing Envelope and Filter Materials

6.8 BLINDING

Blinding is the process of placing bedding materials (sand-gravel materials, etc.) on top and around drains. All drains should be blinded immediately to maintain alignment and to protect the drains from falling rocks, trench cave-ins and backfill operations.

Blinding is not necessary where drains are installed by trenchless ploughs.

6.9 BLIND INLETS

Blind inlets are used to permit surface water to percolate into the subsurface drainage system. They are often used in low depression areas to remove the surface water quickly. The blind inlet is constructed by backfilling the drain trench with various sizes of materials.

The coarsest material is placed over the drain with the size of material decreasing towards the surface. Unfortunately the material placed above the drain is seldom designed as a proper filter, tending to limit its effectiveness.

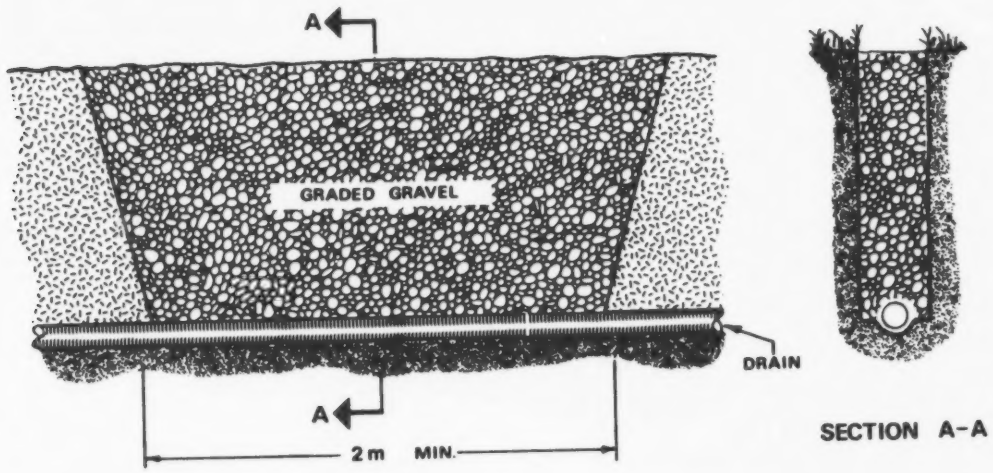


Figure 6.10 Blind Inlet

6.10 BACKFILLING

Backfilling constitutes the materials which are returned to the trench after the drain has been installed and properly blinded. Excavated materials are normally used as backfill. Under special conditions such as steeply sloping land, impermeable soil or an impermeable stratum near the drain depth porous backfill is used to increase the drain effectiveness. Backfill materials should not be compacted artificially, settling should be allowed to occur naturally.

6.11 BREATHERS

Breathers allow air to enter the drain for the purpose of venting the line. They are appropriate when the line is longer than 400 m or where the line changes from a flat to a steep grade ($\geq 5\%$) with full flow in the line during the flat grade (See Figure 6.11).

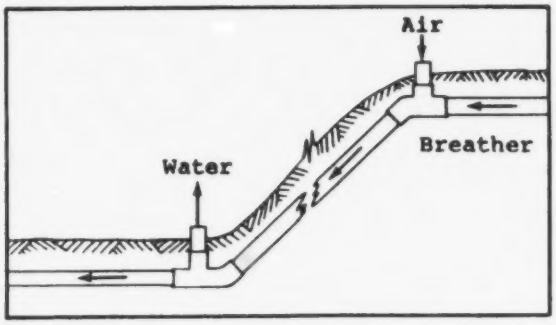


Figure 6.11 Relief Well and Breather.

The standpipe should be 100 mm in diameter when using drain lines 400 mm and smaller and 150 mm when using drain lines 450 mm or larger. To ensure proper flow, cover the top of the standpipe with some type of perforated cap (See Figure 6.12).

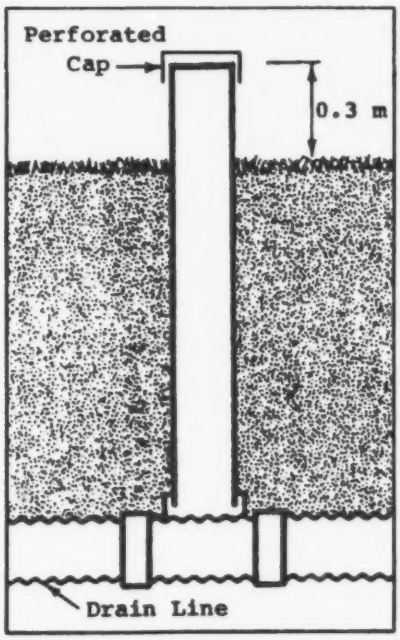


Figure 6.12 Breather or Vent

6.12 SEDIMENT TRAPS AND JUNCTION BOXES

When two or more drains join at different elevations or when drains change direction abruptly it is recommended that a junction box is used. (See Figure 6.13).

The junction box can also function as a sediment trap. They are placed downstream from surface-water inlets to catch sediment and trash in the drain line. The junction boxes should be located in noncultivated areas if possible. Be sure that the capacity of the outlet lines equals the combined capacity of the incoming drains and the outlet drain is at or below the elevation of the lowest incoming line. If possible provide easy access to the box for regular inspection, or if the box is in a cultivated field the top of the box should be at least 0.40 m below the ground surface.

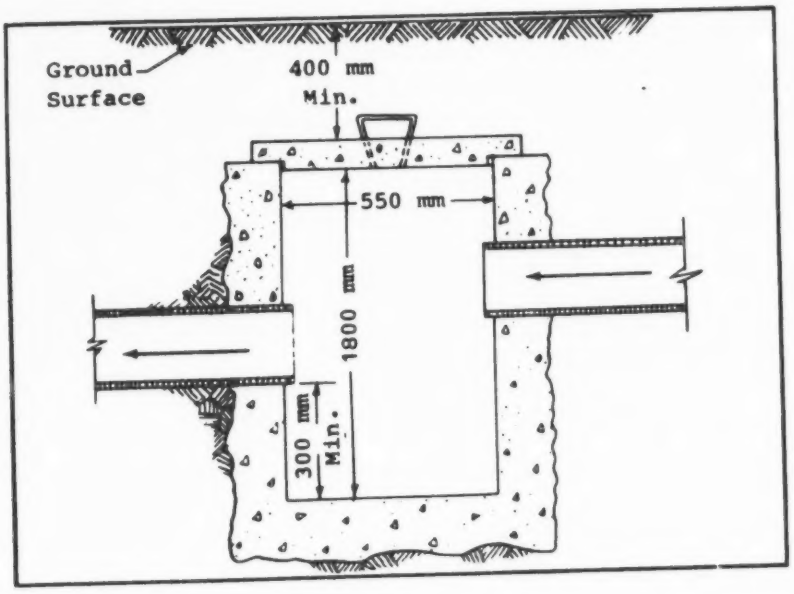
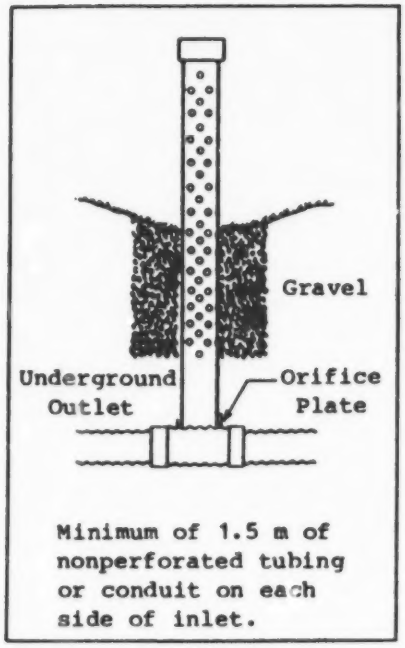


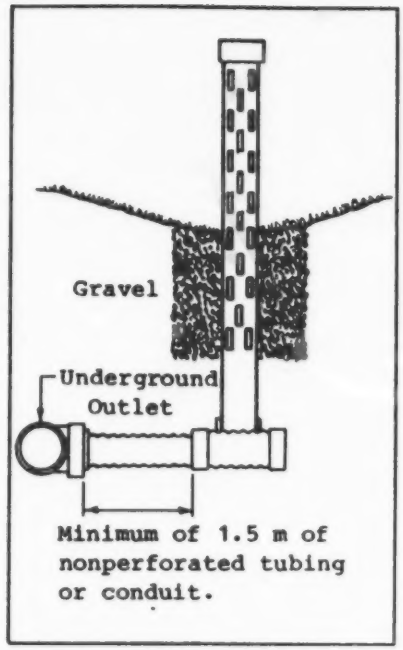
Figure 6.13 Sediment Trap or Junction Box

6.13 SURFACE INLETS

When construction of surface drains to remove surface water or ponded water is not feasible a surface inlet may be used. The surface inlet may also be used to carry extended flows that would normally be carried in a grassed waterway. Surface inlets should be installed on laterals or at least 2.4 m to one side of the main drains. The installed surface inlet should be equipped with screens or trash racks to prevent floating debris from entering. The inlets should also be constructed to withstand crushing loads of agricultural machinery. Surface inlets not projecting above the surface should be protected with a cone grate. Figures 6.14 and 6.15 indicate different types of surface inlets. Open surface inlets are used in situations where shallow surface drains are not practical.



A surface-water inlet connected directly to a subsurface drain line. Typically the length of the riser is 1.5 m.



A surface-water inlet offset from the subsurface drain line to reduce potential damage to the line.

Figure 6.14 Various Surface Inlets

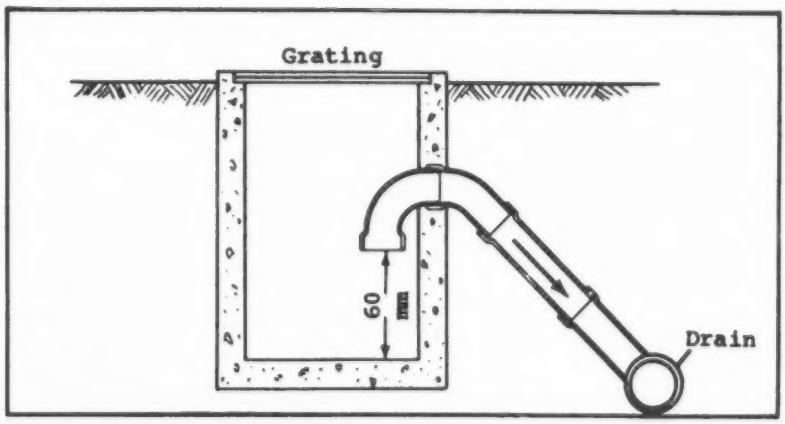


Figure 6.15 Open Surface Inlet

VII OUTLETS

7.1 EXISTING SUBSURFACE DRAINS

When an existing subdrain is used as an outlet for a drainage system, examination of the existing drain is needed. It should have sufficient capacity to carry the flow from the proposed drainage area and should be deep enough to allow all drains in the proposed system to be installed at the optimum depth.

7.2 OPEN DITCHES

Similar to subsurface drain outlet, open ditch outlets should have sufficient capacity to convey the flow from the proposed drainage system. The ditch should be deep enough to provide a free outlet and adequate cover for all outleting drains. (See Figure 7.1)

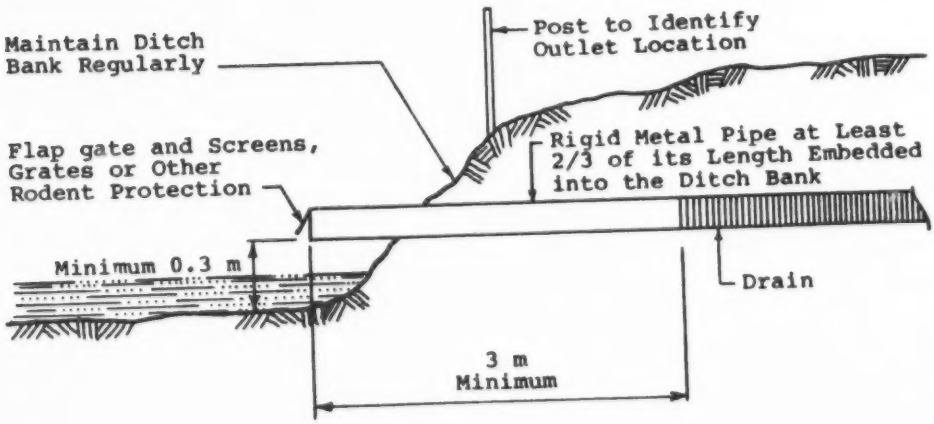


Figure 7.1 Gravity Drain Outlets

There should be a minimum clearance of 0.3 m between the bottom of the drain outlet and the ditch bottom. This clearance should be increased to 0.5 m if the ditch is subjected to sedimentation. Outlets should be in free flow during the growing season.

When drains outlet into an open ditch, a minimum of 3 m of continuous rigid pipe should be used at the end of the drain. At least 2/3 of its length should be embedded into the ditch bank with the overhanging length discharging at the toe of the ditch bank.

The outlet location should be marked with suitable flagging or stakes to permit easy location of the drain when the ditch bank is grassed. Refer to Section 5.2 for ditch slope and dimension recommendations.

Screens, grates or similar protection should be used on all outlets to exclude small animals. These outlets should be inspected on a regular basis for damage and debris trapped in the grating. Figure 7.2 indicates some outlet protection methods.

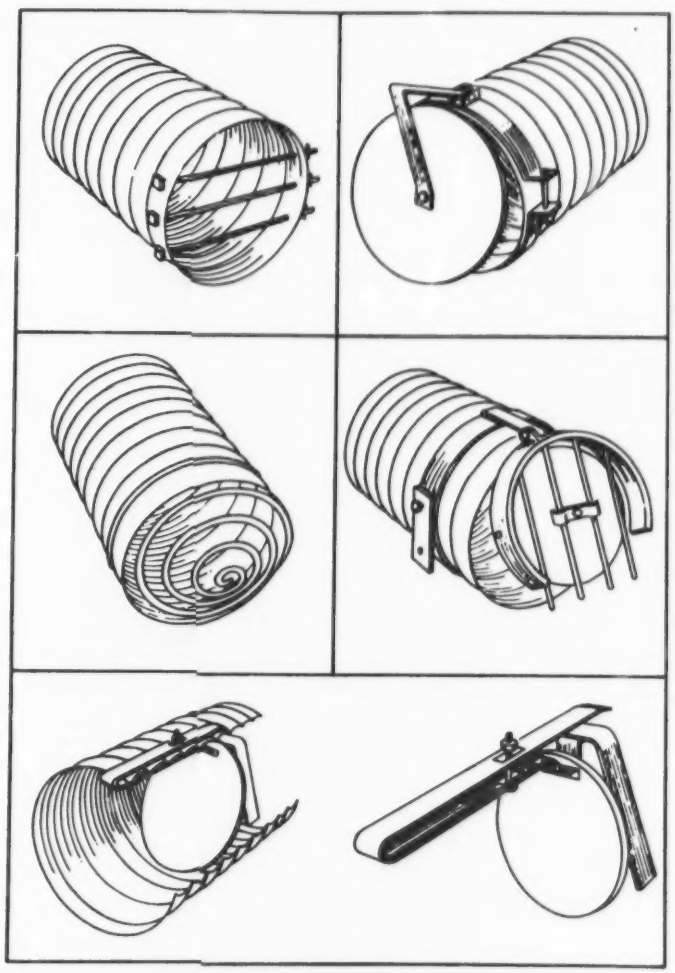


Figure 7.2 Rodent Protection For Outlet Pipe

7.3 PUMPING OUTLET DESIGN

On-farm drainage pumps may be required for several reasons:

1. The regional drainage system provided by the local government authority may not provide an adequate gravity outlet for the poorly-drained farmland.

2. In certain cases a small pump may provide a more economical outlet than a lengthy subsurface drainage pipe or a deep outlet ditch.

The pump station must be designed to pump enough water to meet the local drainage requirements against the maximum total head (elevation and friction) expected. As well, the efficient operation of the pump should be considered.

A topographic survey is useful as preliminary information to determine whether a pumped outlet is required. In the event that a pump station is necessary, the survey can be used to evaluate one or more pump station arrangement to select the one that is the most economical and practical.

Pump Location

The main considerations in establishing the location of a pump station are the proximity to the outlet and the location of the lowest areas of the drainage basin. If possible a pump should be located directly adjacent to the outlet. This limits the pumping distance and therefore the size of the pump. However, in some cases it may be advantageous to locate the pump closer to the electrical power supply. This may also be done to avoid the cost of installing an expensive collection system consisting of pipes or ditches. In such cases a shallow discharge pipe leading to the point of outlet may be less expensive.

If possible, place the pumping plant in a readily accessible location year round. The susceptibility to vandalism may be a consideration in selecting the location and the type of pump station.

Pump stations require stable foundation soils. Before deciding on a site ensure the location has suitable soil strength.

Installation and operation of pumps can be costly. Therefore, where possible, runoff from high ground should be diverted from the pumped area by gravity flow to a suitable outlet. This is often possible if the watershed contains areas of high land adjacent to the poorly drained farmland. Diversion ditches or dykes can be used to intercept water from the upland area and carry it directly to the outlet, bypassing the pump. This can greatly reduce the volume of water to be pumped and thereby reduce the costs of the pump station.

Pump Station Design

There are four main steps in designing a drainage pump station:

Total Dynamic Head Calculation

The intake elevation of the pump depends on the type of drainage system, the water level requirements of the farmland, and the type of collecting system. For a subsurface drainage system, the water level in the sump should not be higher than the invert elevation of the lowest drain outlet.

The discharge elevation of the pump depends upon the physical characteristics of the pump's outlet. There are two general arrangements of the outlet pipe that can be made depending upon the water level elevations in the outlet channel:

i) If the water level elevation in the outlet channel is relatively stable and the maximum elevation is known, set the discharge pipe just above the maximum water elevation. This provides for a free outlet from the pump at all times.

ii) If the outlet water elevation varies considerably, the discharge elevation can be set near to the lower levels as long as the outlet pipe is fitted with a tight flap gate to prevent backflow during periods when the discharge pipe is submerged.

The total head (dynamic or total energy head, H_t) is a combination of three factors:

$$H_t = H + H_v + H_f$$

where:
H = static head
H_v = velocity head
H_f = friction head

i) Static head (H) is the vertical distance between the free water surfaces at the suction and discharge sides of the pump (m).

ii) Velocity head (H_v)

$$H_v = 82{,}550 \frac{(Q^2)}{(D^4)}$$

where:
Q = pump capacity (L/s)
D = discharge pipe diameter (mm)
H_v = velocity head (m)

iii) Friction head (H_f) represents the pressure loss between the entrance and discharge sides of the pump installation. In most cases the only friction loss that must be accounted for is that lost in the inlet and discharge pipes. This head loss can be very significant if, for example, the pump must be located some distance from the final outlet.

Pipe friction losses vary depending on the flow velocity, the pipe diameter and the type of pipe. H_f can be obtained from a variety of charts or tables which are available from the pump supplier or engineer. Appendix D contains friction loss charts for some commonly used pipe materials.

The maximum flow velocity for open ended discharge pipes should not exceed 2.25 m/sec. (identified by dark lines on friction loss charts.) If the discharge line contains valves or other restrictions the maximum flow velocity should not exceed 1.5 m/sec.

Pump Capacity

Pump capacity is based on the drainage requirement. It can be estimated by using local knowledge of drainage system requirements, or through more detailed hydrologic investigations. For small farm sized pumping stations (under about 50 ha) capacities based on local experience are usually adequate and more detailed investigations are not justified. Factors affecting the drainage requirement include climate, topography, soil, land use, and the types of crops.

The capacities shown in Table 7.1 are based on experience.

Table 7.1 Pump Capacity

Region	Pump Capacity litres/sec/ha
Vancouver Is & Gulf Islands	3.0
Lower Fraser Valley	3.0
North Side of Fraser River	4.0
Upper Fraser Valley (Agassiz)	4.5
Pemberton	6.0
Kootenays	2.5
Okanagan	2.0
Cariboo	3.0
Peace River	3.5

When drainage water is from subsurface sources only (no surface runoff) the pumping capacities shown in Table 7.1 can be reduced by 50%. Pump capacities can also be determined by using peak runoff calculations shown in Appendix B.

Pump Type and Power Unit

Low head and high volume are typical of most farmland drainage pumping requirements. Axial flow or propellor pumps are especially suited to these conditions.

In situations where head requirements are greater than about 3 m, a radial or mixed flow type of pump may be more suitable.

Once the pumping capacity and total dynamic head have been determined the power requirements can be estimated by the following formula.

$$P = \frac{QH_t}{102\ E}$$

where: P = power requirement (kW)
Q = pump capacity (L/s)
H_t = total dynamic head (m)
E = total pump efficiency as a decimal fraction.

Pumping efficiencies generally range from about 0.75 at best, to as low as 0.20. A well designed pump should have a total efficiency of 0.70 or more. Unfortunately, many commercially available small on-farm drainage pumps are much lower.

The most convenient power source for pumping plants is electric motors. Single phase motors are practical up to about 5.5 kW. Motors larger than 7.5 kW will normally require three-phase power. Electric motors are usually direct drive.

Electric motors are well-suited to automatic pump operation. Automatic operation is usually obtained using float switches controlling a magnetic starter on the pump motor.

Internal combustion engines are not recommended except for emergency or auxiliary pumps or where electrical power cannot be brought in at reasonable cost. Semi-automatic controls can be added to combustion engine driven pumps to stop the pump when the water level drops to a certain level, or when the pump runs dry.

Water Storage to Limit Pump Cycling

To prevent the motor from starting and stopping too frequently water storage must be provided between the start and stop pumping elevations. For small pumps this storage can be built into the pump sump. For larger systems or for manual pump operation a large open sump or ditch may be required.

The volume of required storage depends upon the pumping rate and the maximum acceptable rate of cycling. It can be calculated as follows:

$$S = \frac{0.9Q}{n}$$

where: S = volume of storage (m^3)
Q = pump capacity (L/s)
n = maximum number of operation cycles per hour

For automatic electric pump operation, cycles of operation should be limited to about 10 per hour. Some of the newer pumps on the market have hardier starter mechanisms and can tolerate up to 30 cycles per hour. Check with the pump supplier to be sure.

For manual operation and especially with combustion engine driven pumps, limit cycling to 2 starts per day (n = 0.08).

Pump Setup for On-Farm Stations

Once the pumping requirements are calculated a pump station can be selected and installed.

The pump station will depend on the pump type, storage type and requirement, and proximity to the outlet. The two most common types of axial pumps are submersible and propellor. Propellor pumps have overhead motors connected with vertical shafts to the pump propellor. Figures 7.3 - 7.6 depict typical installations.

Submersible pumps typically require no pumphouse as the pump sits directly in the sump pit. For small capacity systems, small submersible sewage pumps are easy to install (Figure 7.3). Specially designed submersible drainage pumps suited specifically for low head, high capacity agricultural drainage are also available (Figure 7.4).

Propellor pumps (axial and mixed flow) with overhead vertical shaft connected electrical motors are available as well. (Figures 7.5 and 7.6) A pumphouse is normally required to protect the motor and controls.

Corrugated steel or prefabricated concrete rings are suitable for the sump construction. A minimum diameter of 1.1 m is suggested. Concrete ballast can be added to the floor if necessary to prevent uplift.

Storage can be provided with buried sump of suitable dimensions or with an open ditch. Where open ditches are used to collect and transfer water to the pump, a trash rack must be used to prevent entry of floating debris into the sump where damage to the pump might occur. The velocity of flow through the trash rack should not exceed 0.6 m/s . Recommended spacing for trash rack bars is shown in Table 7.2.

Table 7.2 Trash Rack Bar Spacing

Pump Diameter	Clearance Between Bars
400 mm	20 mm
450 to 600 mm	25 to 40 mm
760 to 1100 mm	50 mm

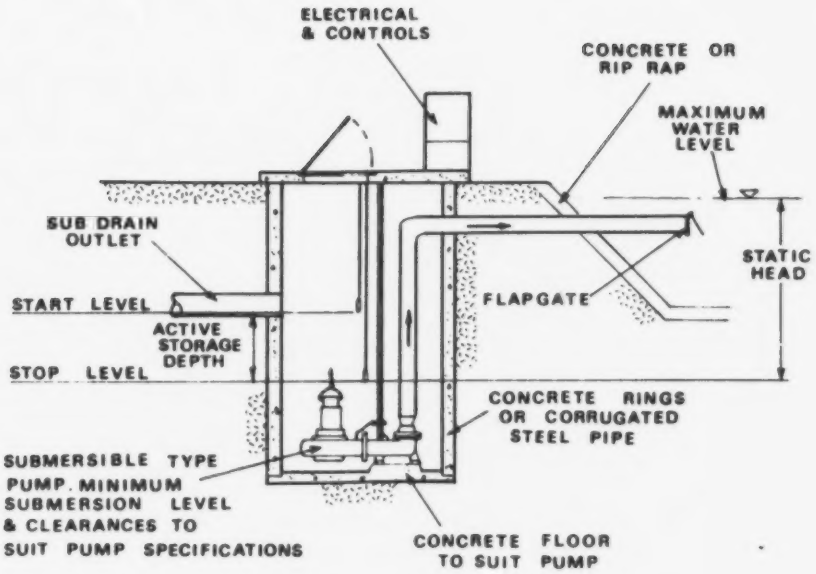


Fig. 7.3 Submersible Sewage-type Drainage Pump.

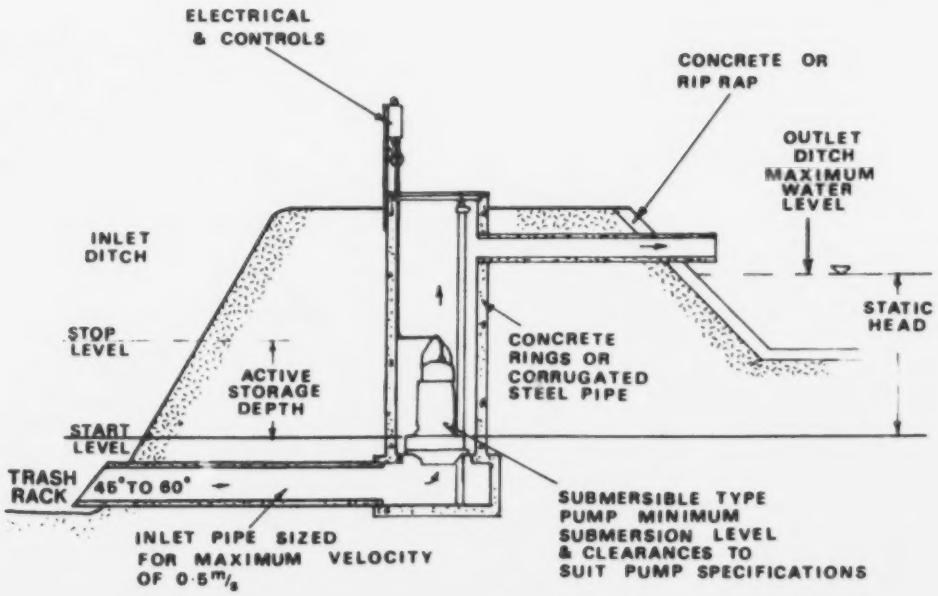


Figure 7.4 Submersible Drainage Pump

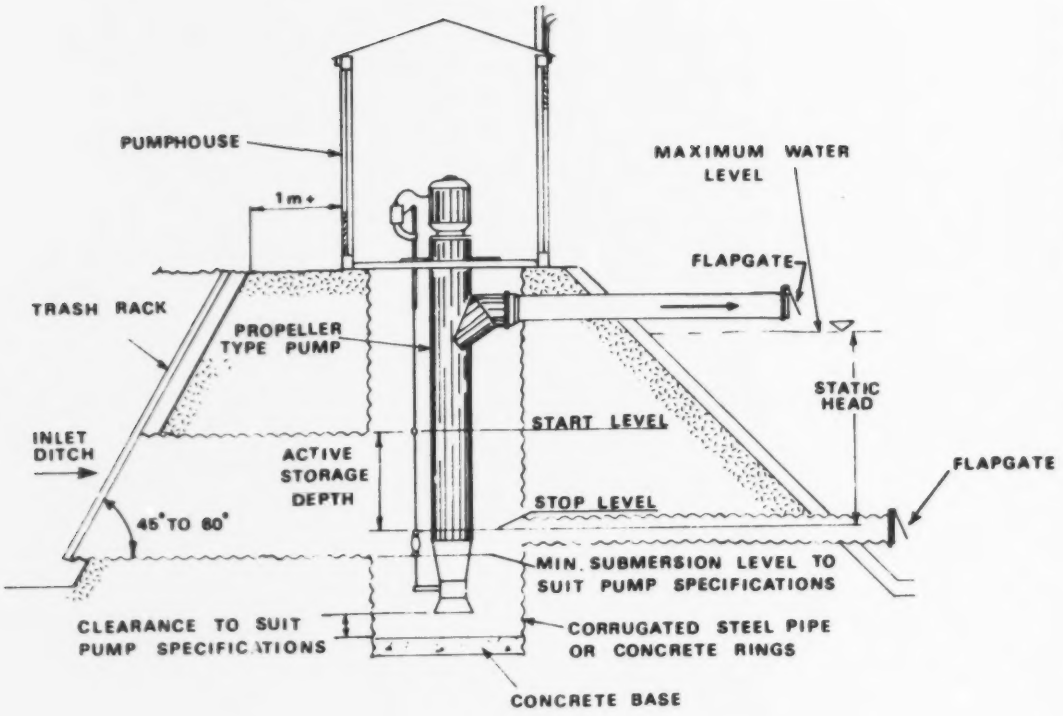


Figure 7.5 Propellor-type Drainage Pump - Open Ditch Inlet

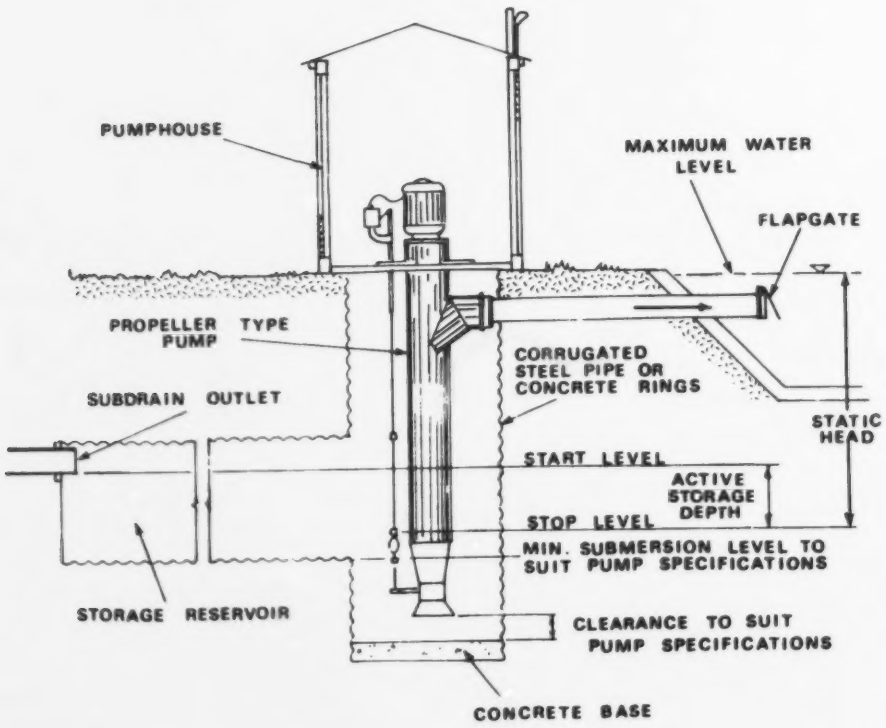


Figure 7.6 Propellor-Type Drainage Pump - Subdrain Inlet

VIII SUBSURFACE DRAINAGE CONSTRUCTION

8.1 METHODS AND MACHINERY

Backhoe

Small tractor-mounted backhoes can be used to install subdrains. They are, however, much slower and therefore, more expensive than drain installation using mechanized trenchers. As well, grade control is difficult, and if grade tolerances are small, constant supervision and likely some hand work will be required to accurately maintain the design grade. Backhoes are only recommended for relatively small jobs where mechanized trenching equipment is not justified, or in regions of the province not serviced by drainage contractors. For a complete description of installation of subdrains using a backhoe see B.C.M.A.F. Engineering Note #543.100.-1.

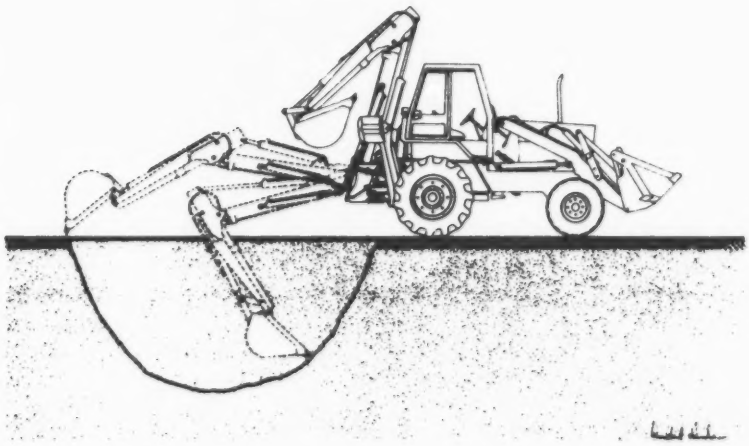


Figure 8.1 Backhoe Installation

Trenchers

Recent advances in trenching equipment have produced machines which excavate using digging chains (See Figure 8.2) or wheels (See Figure 8.3). This equipment is mounted on specially designed crawler or four-wheel drive tractors. Trench depth is regulated by hydraulic control, which lends itself to various feed-back adjustment systems. Equipment is capable of trenching depths of 2 m and greater, and under optimum conditions, of installing drains at the rate of 10 m per minute.

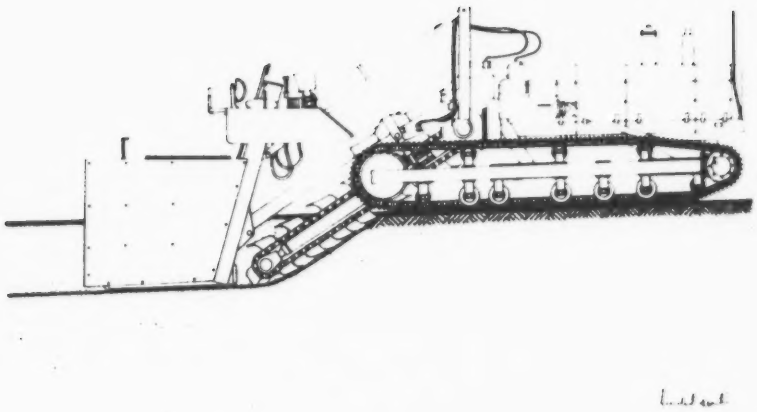


Figure 8.2 Chain-Type Trencher

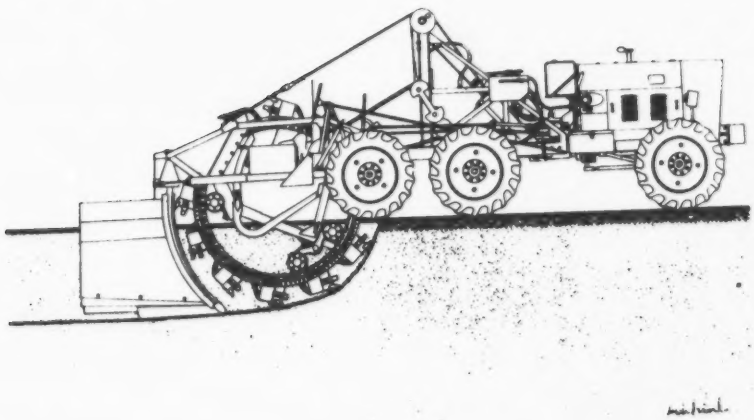


Figure 8.3 Wheel Type Trencher

Plastic drain pipe laid in the bottom of an open trench must be backfilled immediately with at least 150 mm of soil to ensure that it is held properly in place. If the water table is higher than the trench bottom the plastic pipe will float!

The pipe grade cannot be inspected by eye. An engineer's level must be used. If you suspect problems obtain a level, or the services of a qualified surveyor.

Inspect the pipe before it is backfilled to ensure that the couplers are secure, any connections are properly made and end caps are in place.

At the end of each day's installation, the completed trenches should be completely backfilled and the end of the drain line stoppered to prevent sediment or debris from entering the line in the event of an overnight rainstorm. Large stones, clods, and heavy direct loading during backfill should be avoided.

Trenchless Plows

Trenchless equipment evolved more recently from mole drainage. Mole drains are circular channels pulled in the soil by a mole plow. Mole drainage is widely applied with some success in the United Kingdom in heavy clay soils with low hydraulic conductivity.

The invention of flexible drain pipe made it possible to use the mole plow technique for pipe laying. A hollow plow blade is pulled through the ground and the pipe is guided into position through the blade. The blade is manufactured as an attachment to a heavy crawler tractor or as an integral part of the drainage machine. On most types, the working depth does not exceed 1.4 m. The shape of the plow blade should lift soil upwards, rather than compress it sideways. (See Figure 8.4).

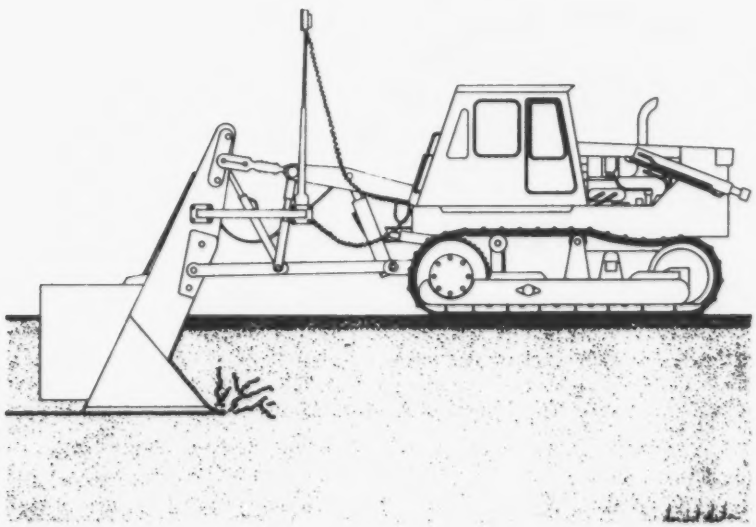


Figure 8.4 Trenchless Plow

Trenchless plows have greater working speed and less wear (due to fewer moving parts) than trenching machines. Plows, however, require a relatively dry topsoil to enable the crawler tracks to develop the high traction required to pull the blade through the ground.

The functioning of drains installed by plows depends upon the changes in soil structure brought about by the passing of the blade. Above certain depths, which vary according to soil and moisture content, heaving and break-up of the soil takes place. Below that depth, deformation and compaction may occur.

The trenchless plow blade is designed to lift and fracture the soil in its path as it moves forward. The slot should be fractured and loosened, not compacted and smeared. Compaction and smearing of the plow slot can occur and depends upon the design of the plow shoe, the soil type, and the soil moisture content. Soils ranging from sands to clay-loams usually fracture readily when plowed. Caution must be used in wet soils with high clay contents. High clay content soils should be plowed when relatively dry. This can result in a high degree of fracturing and cracking which will improve water movement to the drains. Plowing during dry conditions however will increase horsepower requirements. Don't pack down the raised land surface following installation. Let the soil dry and then disc it.

Depth and Grade Control

The depth and grade of subdrains are controlled by sighting targets installed before the drain are laid. Visual sighting by the machine operator of pre-set range poles or grade stakes, and manual adjustment of the desired depth and grade.

The preferred method developed in present years, is with automatic depth and grade control using a laser light beam. This system consists of a command post mounted on a tripod in the field, and a receiver and control unit mounted on the machine. The laser beam is rotated in a plane, tilted according to the required drain gradient. Installation depth is hydraulically adjusted based on where the laser beam hits the receiver.

Some variation in grade can be tolerated when the capacity of the drain exceeds the required capacity. No reverse grade should be allowed. As a guide, construction grade should not deviate from design grade more than 15% of the internal diameter for drain sizes of 200 mm or less, or 10% of the internal diameter for sizes greater than 200 mm. These deviations are allowable only if they are gradual over a distance of not less than 10 m.

If the trench is excavated below grade for any reason, it should be filled above the planned grade with gravel or well-pulverized soil and tamped to provide a firm foundation. The trench bottom should then be reshaped to the planned grade line.

8.2 DRAIN PIPE MATERIALS

Clay drain tile was the most widely used conduit for sub-drainage for many years. It is available in 0.3 m lengths, although 1.0 m lengths are available for outlet sections. Minimum quality standards for clay drain tile are set out by the American Society for Testing and Materials (ASTM) Designation C4 and Designation C4989.

Concrete drain tile is available as well. Because considerable variation can exist in concrete quality, ensure that it meets the minimum specifications as set out by the ASTM Designation C412.

Corrugated Plastic Drain Pipe is the industry standard today. Lightweight, ease of handling, low labour requirements, and suitability for use in unstable soils are some of the reaons for its popularlity. It is commonly available in nominal inside diameters ranging from 100 mm to 300 mm. Minimum quality standards are set by the Canadian General Standards Board, 41-GP-29M (Corrugated Plastic Drainage Tubing). These standards specify a water opening area not less than 16 cm^2/m of tubing length. Perforations are usually provided by transverse saw slits about 1.6 mm in width uniformly spaced about the circumference of the tubing.

IX MAINTENANCE

9.1 SUBSURFACE DRAINAGE SYSTEM MAINTENANCE*

Carefully installed subsurface drainage systems normally require very little repair after the first two years following installation. However, if the minor repairs which may be required are neglected, damage to the drainage systems will become more extensive and major and expensive reconstruction may be needed.

Familiarize yourself with the plan and layout of drains in the field. Learn the locations of the outlets and the boundary of the area served by each outlet.

Some of the most important points to be checked in order to ensure full performance of a drainage system are presented here. In a later section, details of diagnosis of malfunctions and related repair work are given.

Inspection of Subsurface Drains

The first year after installation of a subsurface drainage system is the most critical period in its life. Careful inspection early in the spring after snowmelt and after a rainy period followed by prompt repairs, if needed, are of great importance. The following are the main items for inspecting a subsurface drainage system:

- Walk along all collectors and laterals a day or two after a heavy rainfall or following the spring snowmelt. Observe the presence of pondings or excessively wet strips, as they may indicate blockage of a drain.
- Check the settlement of backfill along the trench especially after the first winter. Deep holes in the backfill may indicate an inrush of surface water due to broken tile or drain pipe. Additional soil should be graded in to fill any sections along a trench where the backfill has settled below the field surface.
- Check for blow-outs or washouts of the trenches in sloping fields.
- It is desirable to remove small bushes and trees that are close to subsurface drainage lines before they develop roots which enter and block the drain.
- Check the outlet pipe for the following:

  a) Stabilitiy of the banks of the outlet ditch; if necessary bring in some soil to fill the area around the outlet pipe. Any such fill should be thoroughly compacted. Stones (rip-rap) can be placed around and below the pipe to stop erosion at the outlet.

  b) The presence of sand or silt deposits inside the pipe. Excessive amounts of sand result from the failure of filter material, collapse of a drain or a loose connection. Filter material may be needed for some spots in the fields which show sand deposit problems.

*Taken from
"Maintenance and Checking of Performance of Subsurface Drainage Systems"
by R.S. Broughton and A.M. Shady, March 1976 McGill University.

c) The colour of the water flowing from the outlet. If the water is cloudy or has an unusual colour it may indicate that surface water is entering the drain directly. Surface water should only enter the drain by seepage through the soil or through a sand trap or gravel-filled trench.
Direct entrance of barn or household wastes into the drain can be detected by the colour of flowing water; it should be prevented at all times. Waste water can spread into the soil through a septic tank and weeping drains. The water could filter through the soil to field drains, but the two systems should not be connected directly.

d) The presence of red to yellow gelatinous sludge or excessive deposits of red crusts may indicate problems related to iron compounds. In this case, you should consult the nearest Agricultural or Drainage Specialist.

e) For submerged outlets, remove some of the sediments at the bottom of the ditch below the outlet pipe to allow direct outflow of water from the outlet to the ditch and to prevent sediments in the ditch from blocking the outlet pipe.

f) Remove any debris that may be found inside the pipe. Ensure the presence of a rodent guard grill at the mouth of the outlet pipe.

g) Replace the outlet marker if it is lost or tipped over.

- Check surface water inlets for damage and trash which seals over the inlet grating obstructing water flow.

Hazards to Subsurface Drainage Systems

- Do not plant willows near drain lines, as their roots can block the drains.
- Never connect a household or barn waste disposal to a subsurface drainage system. Waste sediments may settle out and the nutrients in the waste may encourage the growth of organisms which can cause blockage and deterioration of drains.
- Avoid direct entrance of surface water to a subsurface drainage system. If necessary install a sand trap or gravel filled trench over a branch drain line to filter out sediments and allow only water to enter the drain.
- Do not drive heavy wagons or machinery along the trench in the first year after installation of the drains. In the first year, the soil has not yet reached its final settlement and may be unable to support the loads of these vehicles without causing damage to the drain tile or to the vehicle itself.

Maintenance and Repairs of Malfunctions of Subsurface Drains

As soon as any malfunctioning of drains is observed, diagnosis and repair work should proceed. This section presents a guide for the diagnosis and the repairs required for the most common malfunctions of subsurface drainage systems.

Ponding

The accumulation of surface water alongside or in the direction of a lateral drain which disappears 2-3 days following a rainstorm may indicate the presence of compacted soil with low permeability in this location. But if the water remains on the surface for extended periods after rainfalls while the rest of the field has dried, it may indicate malfunctioning of this drain, possibly a broken tile or damage tubing. To verify this, mark the location with stakes and then in the dry period, dig out the subsurface drain at a location downstream from the ponding. Make an opening in the drain pipe and push a plumber's snake along to check for a blockage in the pipe. Repeat the digging at the place where the broken part is located. Replace this section of pipe carefully with tubing or tile of the same size and backfill again. Care must be taken to prevent the soil from entering the drain during repair work, that is why it is best to do the work during the relatively dry period. If the water flow rate in the drain is small and no blockage of the pipe is found, this indicates low permeability of the soil near the drain. In this case slow drainage is due to the soil and not the drain pipe. A surface drain may be required to drain this part of the field in addition to the existing subsurface drains.

If the surface water is flowing to a ponding and not draining away fast enough to the subsurface drains, some land smoothing or filling and possibly a surface drainage furrow or ditch may be required. One or a combination of these solutions will help in diverting the surface water from the pondings. This will help to make the whole field suitable for tillage or other operations at one time.

Blowout

A blowout is characterized by the flow of water from underground to the surface in a location where there is a subsurface drain. This occurs especially after a heavy rain and indicates that a pipe has been broken or has separated resulting in the flow of water being restricted downstream from the blowout. The water flowing from upstream builds up pressure which can force the water to rise to the ground surface.

Blowouts are probable in a land with a steep grade and at the connections of drain lines. The repair work should be carried out during a dry period to avoid having a soupy condition in the trench. A trench can be dug along the location of the damaged pipe, usually downstream of the blowout. The damaged pipe should be replaced by a new section of pipe or tile of the same diameter, and the trench should be backfilled with soil and compacted around the pipe.

Trench Washout

A washout of the trench is the removal of the backfilling soil and materials from the trench by erosion due to the rapid flow of surface water along the trench. In some severe cases of washout, the drain pipe may be partially or totally exposed or washed away, and the sides of the trench may be badly eroded. This has happened in trenches of steep grade in the first year after installation during exceptionally heavy rain storms or during the spring runoff.

There are several factors that may cause a washout after rapid surface runoff. These factors include: the instability of backfilling of the trench, saturation of the soil in addition to possible pressure build-up in the drain pipe.

During a relatively dry period, the repair work may proceed following these steps:

a) Clean out the debris and loose soil from the trench.
b) Dig up the exposed tile or tubing, examine it and discard if damaged.
c) Place the new tile or tubing, the same diameter as the old one, on firm ground at the bottom of the trench and keep the pipe on a constant grade.
   If the existing trench is badly eroded at the bottom, dig a new trench nearby at the same grade and place the drain in it. Connect both ends carefully to the rest of the drain line.
d) Backfill the trench with soil, and compact it around the drain, and allow extra soil to be left on the top of the trench for future settlement.
e) Make certain that loose soil does not enter the drain during the repair, and if the original drain is wrapped with a filter material, the new line must also be wrapped with a good quality filter material.
f) If the washout has been on a steep section of a collector line, it is probably best to replace this section with a non-perforated corrugated plastic drain tubing of equal diameter. If this section of collector pipe was intended to provide subsurface drainage as well as collector drainage, a perforated 75 mm or 100 mm diameter lateral pipe could be installed in a new trench nearby, or carefully installed 0.15 m above the collector pipe on compacted soil in the same trench, provided there is 0.60 m of cover for the special lateral pipe.

Erosion at Drain Outlet

When a subsurface drainage system has an outlet into a gully or creek with steep side slopes in areas where landslides are known to have occurred, erosion at the outlet site might occur during the spring runoff. The severity may range from slight bank erosion to a sizeable landslide. If either case occurs, corrective measures should be taken to stop any further extension of this erosion as soon as soil conditions permit working around the affected area.

The following steps may be taken:

a) Dig up the affected outlet pipe and drain tile or tubing until firm ground is reached.
b) Place a new section of non-perforated colletor pipe of the appropriate diameter on grade on firm soil with adequate cover (at least 0.60 to 0.90 m). Compact the soil around this section of drain pipe.
c) Grade the eroded bank to a gentle slope of at least 2.5:1 side slopes, compact it, and seed it with an appropriate grass to stabilize it.

d) Prevent surface runoff from the field from passing over this affected area by digging a shallow diversion channel to direct surface water into the ditch in an area where the bank is stable. Use a drop structure if necessary.

e) In some cases where the side slopes are very steep and the bottom of the watercourse is deep, liners, cribbing or a sheet metal retaining wall, or gabion baskets may be used to protect the bank from erosion by placing them to form a wall parallel to the bank and anchored into firm ground.

Blocking of Drains by Sediment

Soils with a high content of fine sand or silt pose a hazard to the subsurface drainage system. The fine particles may flow into the drains and block them unless they are protected by a filter wrapping. If appreciable quantities of particles enter the drain, most of it remains inside the drain pipe reducing the available space for conveying water. To prevent this, the tile or drain tubing should be wrapped with filter material before or during installation to stop the fine particles from entering the drain. If the filter material is not of an appropriate kind, or if it is not placed all around the drain, fine sands and silts may enter the drain and block it.

Drain blockage can be observed by inspecting the outlet pipe first. If it shows accumulation of silt or fine sand, then the collector (the main) and possibly some laterals are affected by these sediments.

The laterals which are blocked can be located by the fact that it takes a longer time for the strip of land served by the lateral to drain comparison to the unblocked laterals in the same field. Digging up the lateral near the connection with the collector (main) will help to find out if either the lateral or collector is blocked. If water is readily available in the location, the drain can be flushed using high pressure water jets and plastic pipe. It is practical to flush out pipes of 150 mm and larger diameter, but it is less expensive and gives a better job to replace a 75 or 100 mm diameter drain pipe than to flush it out. Any pipe replaced due to blockage with sediment should be replaced with a filter-wrapped pipe.

Drains Blocked by Roots

Water-loving trees such as willows and elms growing near the drains may extend their root system to the drain in search for water during the dry season. The roots enter the drain through the openings or joints and extend themselves in the drain reducing the effectiveness of the drains in conveying weater. When this happens, the area upstream will take a longer time to dry and may have water on the surface for extended periods. Digging a trench near the tree down to the drain will verify the root growth. If the tree is not essential, remove the tree and replace the affected section of drain pipe. If the tree is to be retained, replace the affected section of pipe with a continuous length of non-perforated pipe at least 60 meters long.

Collapsing of Drain Pipes by Heavy Loading

The subsurface drains are normally installed in the field with adequate cover of about 0.60 to 0.90 meters or more. This cover is enough to prevent collapse of the drain from normal loading by common farm vehicles and equipment. The deeper the drains, the more protection it has against heavy loads. However, in some instances, heavy equipment may be used in the field for non-agricultural purposes. Under some unfavourable conditions, with the presence of stones adjacent to drains, shallow cover, very soft soil, and excessive or repeated loading by heavy equipment may cause deep ruts and crushing of the drain pipes. The result is a reduction of the water flow in the drain, which may be observed by the presence of wet strips along the affected drain and in some cases a blow-out may occur upstream from the crushed drain. In such a situation, the damaged drain can be located, dug up, and replaced by tubing or tile of the same diameter. Backfill the trench carefully removing any stones from the soil used (extra backfill is to be left on top of the trench for future settlement). Shallow drains crossing laneways should be replaced by a steel pipe.

Iron Oxides Blockage

In a few soils, iron compounds may be deposited around the drain forming an insoluble crust which can block the opening of the drain or filter materials around the drain and reduce the amount of water flowing to the drain. Some compounds enter the drain and are deposited inside or encourage a growth or organisms forming of gelatinous sludge which may cause blockage along the drain. The cause of these phenomena is not clearly known. Recent research suggests that some microbial and chemical reactions under certain climatic and soil conditions may lead to precipitation of iron compounds or sludge formation. An indication of the presence of such a problem is the presence of deposits of a hard crust or gelatinous sludge (red to yellow color) in the outlet pipe. If the effectiveness of the subsurface drainage system is reduced by this problem, the drains can be flushed with a pressurized water jet. This flushing may help to get the system operative for some time, but cannot stop the problem from recurring. Research work is underway in Canada, United States and Europe to obtain a better understanding of this problem and find some possible solutions.

9.2 WATERCOURSE MAINTENANCE

Open ditches convey excess water from the field to larger river channels. The hydraulic capacity of a ditch is reduced if it is silted up, blocked by debris or weeds. This results in a reduction of amount of water removed from the field and flooding of the adjacent field may occur. Maintenance of open ditches must be exercised continually, especially for those serving as outlets for subsurface drainage. The following items are recommended to be observed:

- Routinely check the ditch and remove all the debris, weeds, silts, etc., from the drain.
- Keep the culverts clean by removing any sediments and debris from the culvert.

- Do not allow livestock in a ditch at any time.

- Use barbwire or electric fences to prevent cattle from grazing on the ditch banks.

- To help stabilize the banks of newly dug ditches, the banks should be seeded with a grass mixture suitable for the soil and climatic region. The root system may stabilize the soil and the grass reduces erosion. This grass may be mowed in subsequent years and reseeded if necessary.

- Some undesirable weeds or aquatic plants may thrive in the ditch reducing its effectiveness. Removal of these plants by buring or by some chemical method is possible, but special permission is required in each case. Check with the appropriate authority in the Provincial Ministry of Agriculture or Environment for regulations concerning use of chemicals or buring. A backhoe or drag line may be needed to remove these plants mechanically if the growth is thick. Some special ditch cleaning buckets for backhoes are now available.

- Some sections of a ditch bank may slough off into the ditch because the soil has insufficient shear strength in a local area. In these special cases, the bank should be cut flatter with a backhoe and reseeded.

- If row crops are planted at right angles to the ditch, do not allow the water in the individual furrows to drain directly into the main ditch. Provide a small collection ditch for disposal at an appropriate location, this will reduce the occurrence of silting of the main ditch.

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APPENDIX A

HYDRAULIC CONDUCTIVITY OF SATURATED SOIL - The Auger Hole Method.

The auger-hole method is a rapid, simple and reliable method for measuring hydraulic conductivity of soil below a water table. A detailed description of its theory and procedures can be found in Van Beers (1958). The general principle is very simple: a hole is bored into the soil to a certain depth below the water table. When equilibrium is reached with the surrounding groundwater, a portion of the water in the hole is removed. The water seeps into the hole again, and the rate at which the water rises in the hole is measured and then converted by a suitable formula to the hydraulic conductivity for the soil. **The measurements must be done when the soils are in a saturated condition.**

The measuring equipment consists of the following:

- A tube, about 60 cm long, the bottom end of which is fitted with a clack valve so that it can be used as a bailer. Extension pieces can be screwed to the top end of the tube.
- A float.
- A light-weight steel measuring tape.
- A standard. The standard is used to press into the soil up to a certain mark, so that the water level readings can be taken at a fixed height above the soil surface.
- A soil auger. It is found that an open blade auger is good for wet clay soils.

Procedure

. Select a suitable site for the hole avoiding high or low spots, and areas close to a ditch or a lane. The site should represent the area of the same soil type. Dig a hole in each soil type, or one hole per 4-8 hectares of a homogeneous soil.

. Using a suitable soil auger dig the hole. The auger should always be perpendicular to the soil surface. Empty the auger when it is filled, observe the soil texture, structure, color and other properties, and record it along with the depth on the observation sheet provided.

. Allow the water table in the hole to reach an equilibrium with the natural groundwater of the soil. Record the depth of the water table and the depth of the hole.

. Remove the water from the hole as quickly as possible after equilibrium is reached using a bailer.

. Using the measuring unit (stand, float, and graduated rod), record the rise of the water in the hole at 15 second intervals by taking the reading off the graduated rod against fixed point on the stand. Take 5-10 readings if possible to obtain a good average. The intervals can be more or less than 125 seconds depending on the conductivity.

- For relatively homogeneous soil, two measurements of hydraulic conductivity can be made in the same hole; the first K_1 to a depth of 120 cm and then the hole can be deepened to a depth of 240 cm to obtain K_2.

- For layered soil, dig two auger holes of different depth to obtain an estimate of the conductivity of each later. A definition sketch for the method is given in Figure A.1.

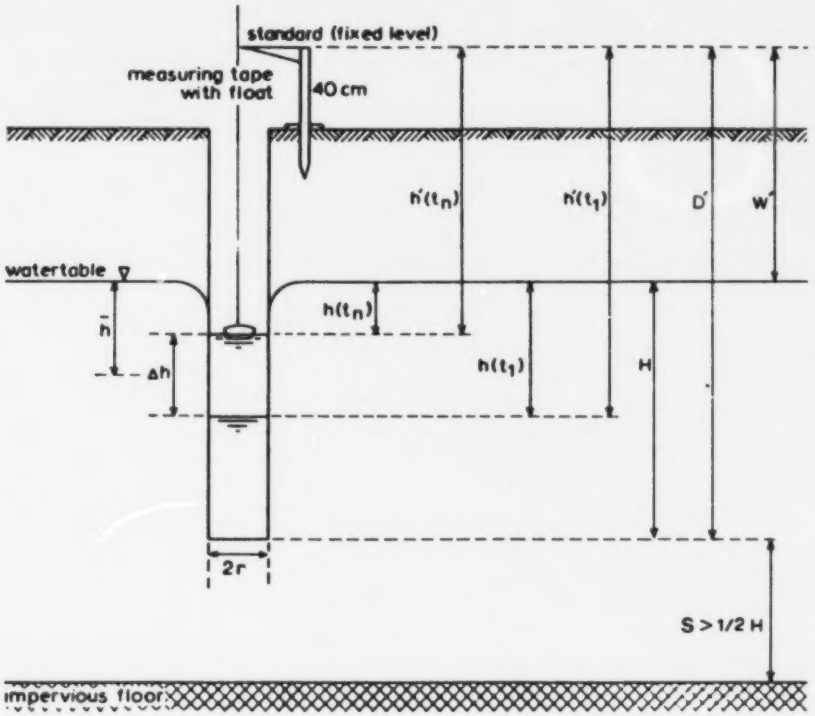


Figure A.1 Definition Sketch of the Auger-Hole Method

where D' = depth of the auger hole below level of the standard.
W' = depth of the water table below level of the standard.
H = D'-W' = depth of the auger hole below water table.

$h'(t_1), h'(t_n)$ = depth of the water table in the hole below standard level at the time of the first reading (t_1) and after some readings (t_n). Usually about 5 readings are taken.

$\Delta h = h'(t_1)-h'(t_n) = h(t_1)-h(t_n)$ = the rise of water level in the hole during the time of measurements.

$\bar{h} = h(t_1) - \frac{1}{2}\Delta h$ = average head during the time of measurements.

S = depth of impervious layer below the bottom of the hole
r = radius of the hole.

Calculating Hydraulic Conductivity

One Layer Problem:

$$K = C \frac{\Delta h}{\Delta t}$$

where

K = hydraulic conductivity, m/day

C = geometry factor = f (h, H, r, s)

$\frac{\Delta h}{\Delta t}$ = rate of rise of water level in the auger hole, cm/sec

Example

A sample calculation for hydraulic conductivity of a one layer problem is shown in the example below.

D' = 240 cm
W' = 114 cm
H = D' - W' = 126 cm

r = 4 cm
S = > ½ H

i	t_i	$h'(t_i)$	Δh
	second	cm	cm
1	0	145.2	-
2	10	144.0	1.2
3	20	142.8	1.2
4	30	141.7	1.1
5	40	140.6	1.1
6	50	139.6	1.0
		Δh = 5.6	5.6

$\Delta t = t_6 - t_1 = 50$ sec

$\Delta h = h'(t_1) - h'(t_6) = 5.6$ cm

$h(t_1) = h'(t_1) - W' = 145.2 - 114 = 31.2$ cm

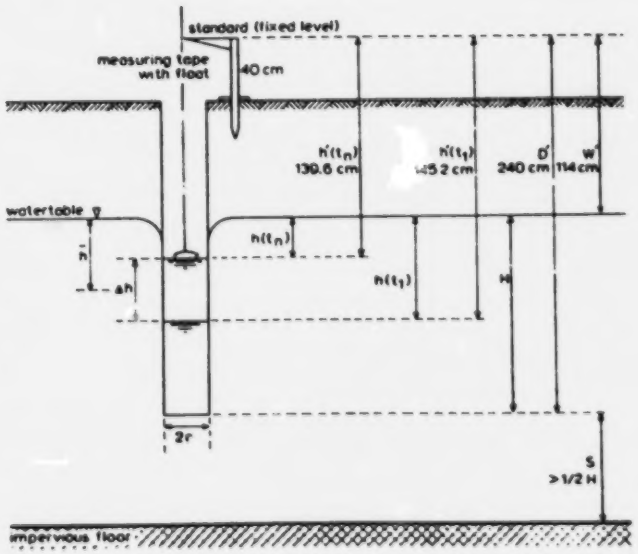
check $\Delta h < \frac{1}{5} h(t_1)$ (5.6 < 7.8)

$\tilde{h} = h(t_1) - \frac{1}{2}\Delta h = 31.2 - 2.8 = 28.4$ cm

H/r = 31.5
$\tilde{h}$/r = 7.1
} C = 6.0 (read from Fig. A.3)

$\Delta h/\Delta t = \frac{5.6}{50} = 0.11$

K = C $\Delta h/\Delta t$ = 6.0 × 0.11 = 0.66 m/day



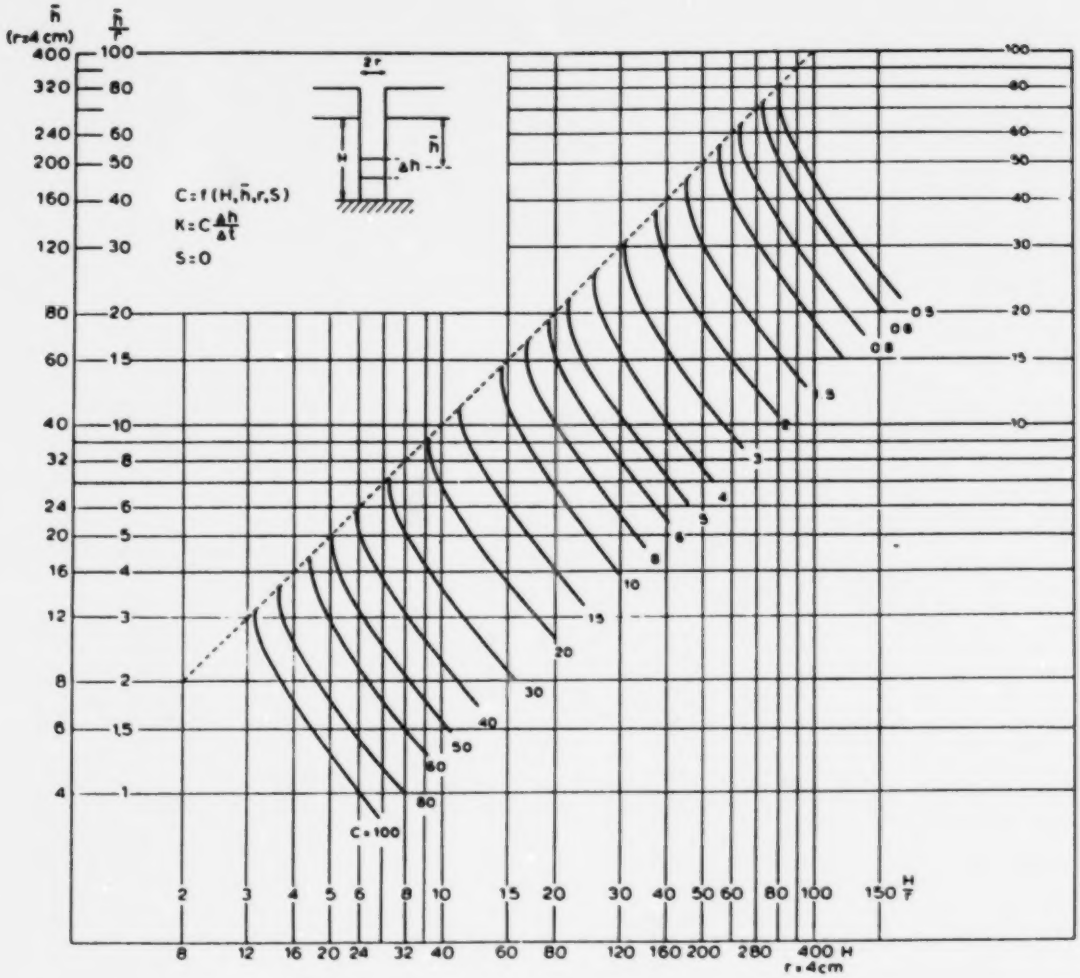


Figure A.2 Nomograph for Determination of C in Auger Hole Method (Ernst 1950)

"C" is given as a function of $\frac{\bar{h}}{r}$ and $\frac{H}{r}$ when S = 0

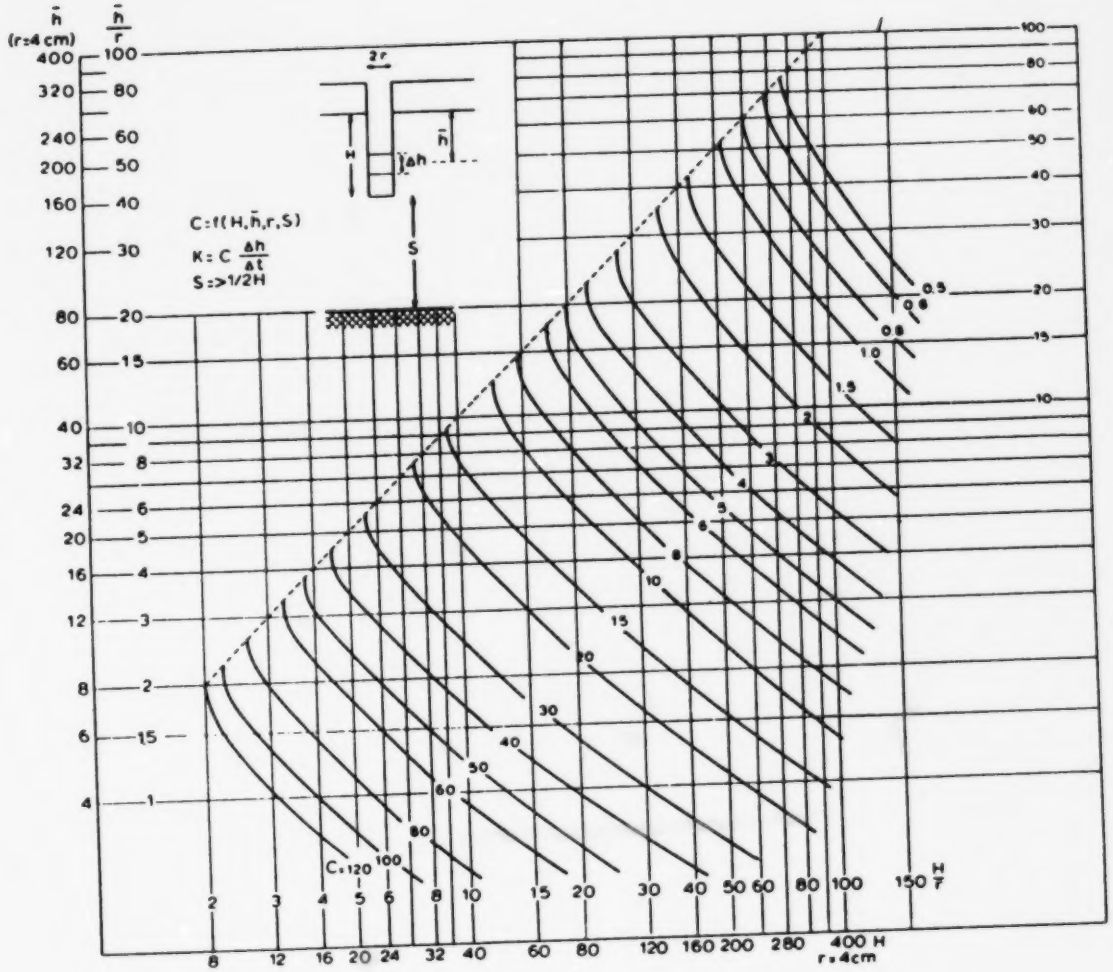


Figure A.3 Nomograph for Determination of C in Auger Hole Method (Ernst 1950)

"C" is given as a function of $\frac{\bar{h}}{r}$ and $\frac{H}{r}$ when $S > 1/2\ H$

Two Layer Problem

If a soil profile consists of two layers of different hydraulic conductivity, K_1 in the upper layer and K_2 in the lower layer, the values for the separate layers can be determined if the water table is well within the upper layer. Two successive measurements must be made in one hole, the second measurement being taken after the original hole has been deepened. A hole is bored to at least 40 cm below water table, but should not extend further than 20 cm above the lower layer. The deepened bore hole must reach at least 50 cm into the lower layer. The measurement in the shallow hole gives K_1, the hyudraulic conductivity of the upper layer, in the same way as for the one layer (homogeneous) soil.

$$K_1 = C_1\left(\frac{\Delta H}{\Delta t}\right)_1$$

where C_1 is a function of $(\bar{h}_1, H_1, r, S_1 > 1/2\ H_1)$

The hydraulic conductivity for the lower layer, K_2, can be obtained from:

$$K_2 = \frac{Co\left(\frac{\Delta h}{\Delta t}\right)_2 - K_1}{\frac{Co}{C_2} - 1}$$

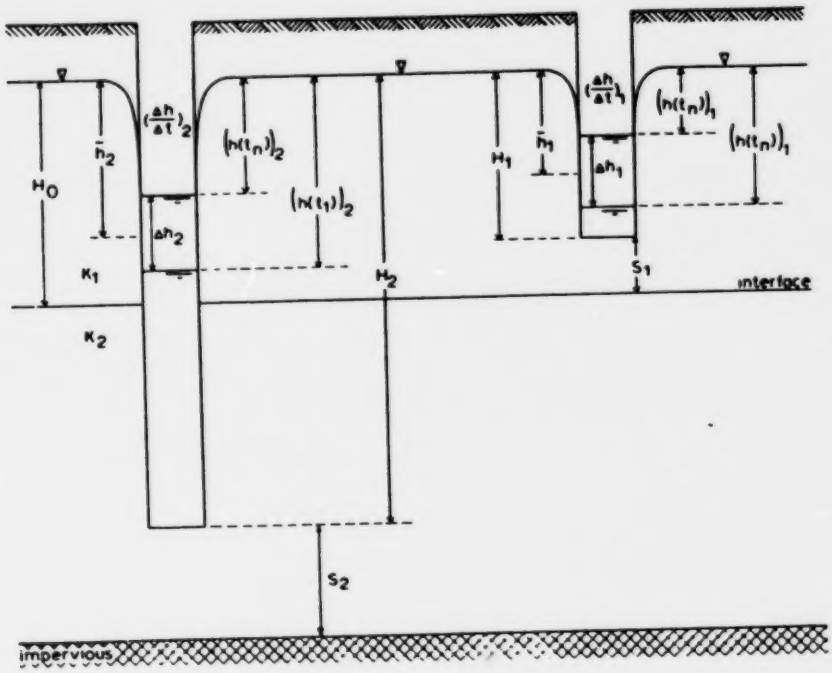
where $\left(\frac{\Delta h}{\Delta t}\right)_2$ = rate of rise of water level in the deepened hole, cm/sec

Co is a function of $(\bar{h}_2, Ho, r, S_1=0)$, from Figure A.3

C_2 is a function of $(\bar{h}_2, H_2, r, S_2 > 1/2\ H_2)$, from Figure A.2

Example:

A sample calculation for hydraulic conductivity of a two layer problem is shown in the example below:



The auger-hole method for the two-layer problem

$(\Delta h/\Delta t)_1$ = 0.16
H_1 = 70 cm
$\bar{h}_1$ = 30 cm
$S_1 > \frac{1}{2} H$
r = 4 cm

C_1 = 9.4 (Fig. A.2)

$K_1 = C_1(\Delta h/\Delta t)_1 = 9.4 \times 0.16 = 1.5$ m/day

$(\Delta h/\Delta t)_2$ = 0.26
H_2 = 150 cm
$\bar{h}_2$ = 40 cm
$S_2 > \frac{1}{2}H$

C_2 = 3.9 (Fig. A.2)

H_o = 100 cm
$\bar{h}_2$ = 40 cm
S_1 = 0

C_o = 6.3 (Fig. A.3)

$$K_2 = \frac{C_o(\Delta h/\Delta t)_2 - K_1}{C_o/C_2 - 1} = \frac{6.3 \times 0.26 - 1.5}{6.3/3.9 - 1} = 0.22 \text{ m/day}$$

APPENDIX B

PEAK RUNOFF ESTIMATION

The objective of runoff estimation is to provide necessary data for the design of agricultural surface drainage systems and farm ponds. It should focus on the amount of water that can be expected to runoff and the frequency that it can be expected.

There are many methods for peak runoff estimation. The two most commonly used methods are outlined in this publication.

The Rational Method is used in Canada and the U.S.A. to predict design flows from small urban and rural watersheds. For rural watershed areas the upper limit for which the Rational Method is valid is 500 hectares. Two significant limitations to the Rational Method are estimating the time of concentration and selecting an appropriate runoff coefficient. The following considerations should be taken into account when using the Rational Method:

- The rainfall intensity used should be uniform over the entire watershed.
- The peak runoff rate occurs when the entire watershed is contributing.
- For a given region, estimates of the time of concentration may be improved by comparing calculated times with recorded times at stream gauging stations.
- Evaluation of soil types and land uses and comparing Rational Method results with stream gauge data may provide better estimates of runoff coefficients.

The Soil Conservation Service (SCS) Method utilizes additional analysis of soil/land characteristics. While this method is more complex the results achieved may be more realistic.

A suggested approach is to use both methods for calculating peak runoff rates. The results should be compared, the analysis procedure reviewed, and appropriate changes made if necessary. An average value of the different results can then be used.

Rational Method

This method is used extensively for many parts of the world including U.S.A. and Canada. The method may be expressed as:

$$Q = 0.00278 \times C \times i \times A$$

where

Q = peak runoff rate, m^3/s

C = runoff coefficient as given in Table B.1

i = rainfall intensity, mm/hr, for the design return period and for a duration equal to the time of concentration of the watershed area

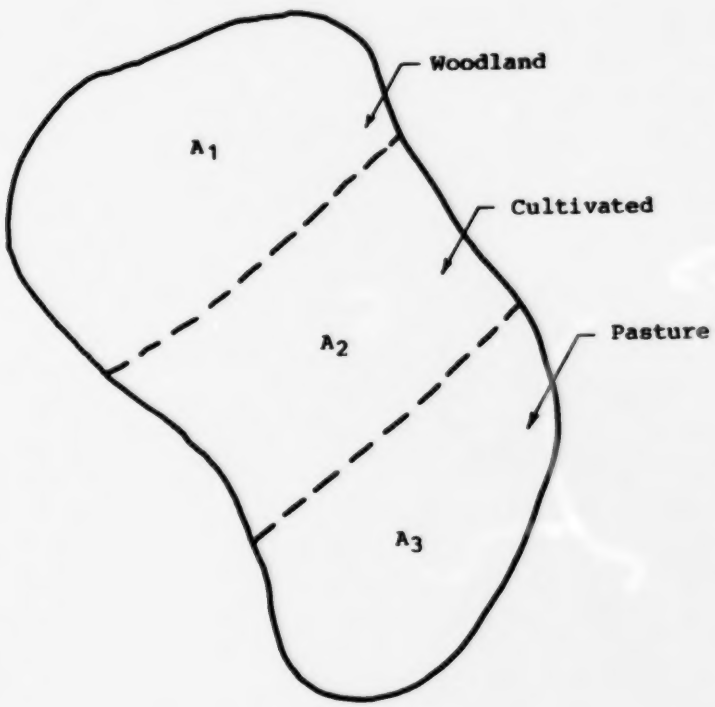
A = effective watershed area, (ha).

The following procedure may be followed for the use of this method:

1. Determine the effective drainage area A (ha).

2. Estimate the runoff coefficient C from Table B.1. For more than one type of topography or vegetation cover C is calculated as follows:

$$C = \frac{\sum C_i A_i}{\sum A_i} = \frac{C_1A_1 + C_2A_2 + C_3A_3}{A_1 + A_2 + A_3}$$



3. Estimate the time of concentration, Tc, for the watershed area from Table B.2 The storm duration for this method is equal to the time of concentration (Tc).

4. From the duration estimated and a selected rainfall frequency, the design rainfall intensity, (i), is obtained from an appropriate figure in Appendix C. Agricultural drainage systems are normally designed for rainfall events of 5 to 10 year return periods.

5. Estimate Q by using the equation $Q = 0.00278 \times C \times i \times A$

It should be noted that this method is not recommended for use on watershed basins larger than 500 hectares.

Table B.1 Runoff Coefficient (C)

Topography and Vegetation	Open Sandy Loam	Clay & Silt Loam	Tight Clay
Woodland			
Flat 0-5% slope	0.10	0.30	0.40
Rolling 5-10% slope	0.25	0.35	0.50
Hilly 10-30% slope	0.30	0.50	0.60
Pasture			
Flat	0.10	0.30	0.40
Rolling	0.16	0.36	0.55
Hilly	0.22	0.42	0.60
Cultivated			
Flat	0.30	0.50	0.60
Rolling	0.40	0.60	0.70
Hilly	0.52	0.72	0.82
Urban Areas	30% of area impervious	50% of area impervious	70% of area impervious
Flat	0.40	0.55	0.65
Rolling	0.50	0.65	0.80

From Schwab (1971)

Table B.2 Time of Concentration for Small Drainage Areas (Tc)

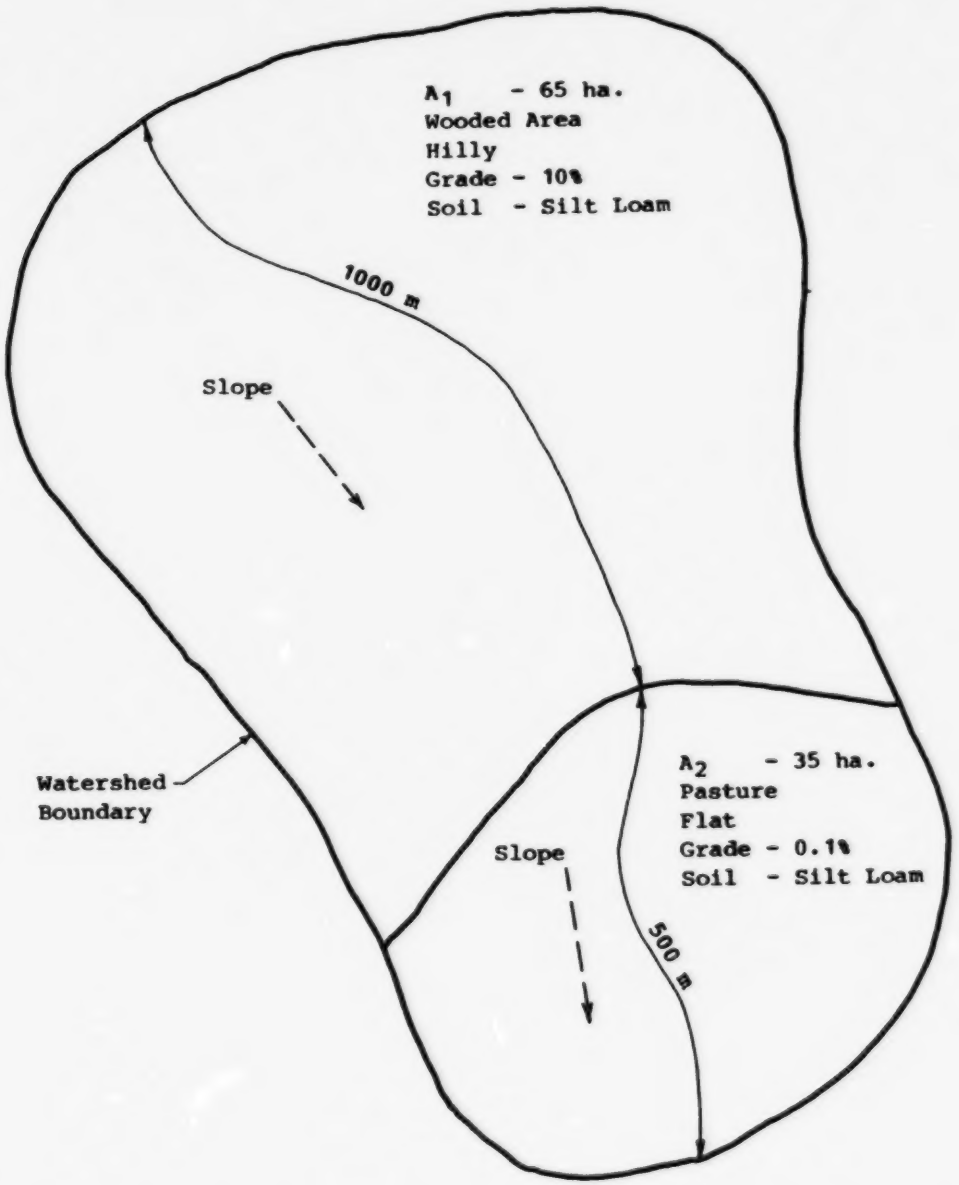
Maximum length of flow (m)	Gradient of Drainage Area (percent)					
	0.05	0.1	0.5	1.0	2.0	5.0
100	13	10	5	4	2	2
200	21	16	9	7	5	4
300	29	23	12	9	7	5
400	37	28	15	12	9	6
500	44	33	18	14	11	7
1000	74	57	31	23	18	13
1500	102	78	42	32	25	17
2000	127	97	52	40	31	22
2500	150	115	62	47	36	26
5000	256	196	106	81	62	44

Generated from $Tc = 0.0195 \times L^{0.77} \times S^{-0.385}$,

where L = maximum length of flow (m)
S = grade of drainage area (m per m)
T_c = time of concentration (minutes)
Gradient = the grade expressed in percent

Example 1 **Rational Method**

A farmer in Abbotsford wishes to construct an open ditch to protect his operation from upland runoff. The watershed area is 100 ha of which 35 ha is being farmed. Calculate the peak runoff based on the information provided in the diagram below.



Example Calculations:

1. Watershed area - 100 ha

2. Runoff Coefficient From Table B.1

$C_1 = 0.50$ for wooded area

$C_2 = 0.30$ for pasture area

$$C = \frac{C_1A_1 + C_2A_2}{A_1 + A_2} = \frac{(0.50)(65) + (0.30)(35)}{65 + 35} = 0.43$$

3. Time of Concentration

For Area 1

$L = 1000$ m

$$\text{Gradient} = 10\% = \frac{10 \text{ m}}{100 \text{ m}} = 0.10 \qquad S = 0.10$$

$$Tc = 0.0195 \times L^{0.77} \times S^{-0.385}$$

$$= 0.0195 \times (1000)^{0.77} \times (0.10)^{-0.385}$$

$Tc = 9.5$ Minutes

For Area 2

$L = 500$ m

$$\text{Gradient} = 0.1\% \qquad S = \frac{0.1}{100} = 0.001$$

From Table B.2 Tc = 33 minutes

Time of Concentration for entire watershed = 33 + 9.5 = 42.5 minutes

4. Rainfall Intensity

From Appendix C

Storm duration = Tc = 42.5 minutes

Storm return period = 10 years

From Figure C.3 Rainfall intensity = 22 mm/hr

5. Peak Runoff

$$Q = 0.00278 \times C \times i \times A$$

$$Q = 0.00278 \times 0.43 \times 22 \frac{\text{mm}}{\text{hr}} \times 100 \text{ ha}$$

$$Q = 2.63 \text{ m}^3/\text{sec}$$

Note: In this particular example, since a large portion of the watershed exists above the agricultural area, an interceptor ditch should be constructed between the wooded area and the field. The ditch size would be based on the peak runoff calculated for the wooded area only.

Soil Conservation Service (SCS) Method

The U.S. Soil Conservation Service (SCS) developed a method to estimate the peak runoff rate. The formula may be expressed as:

$$Q = \frac{0.00208 \times A \times q}{(0.5 \times D) + (0.6 \times Tc)}$$

where Q = peak runoff rate, m^3/S

A = drainage basin, ha

q = the runoff volume, mm over the drainage area

Tc = the time of concentration, hr

D = the storm duration, hr

The following procedures and information may be used for application of this method:

1. Determine the drainage basin area, A.

2. From knowledge of the drainage area characteristics, determine a runoff curve number from Tables B.3 and B.4. This number represents a runoff index for average antecedent moisture conditions and may be modified for wet or dry conditions as given in Figure B.1.

3. Estimate the time of concentration, Tc from Table B.2.

4. From knowledge of rainfall characteristics in the region, storm duration, D, is determined. D may be estimated from D = (0.7 x Tc). **Note: Tc is measured in hours.**

5. From the estimated D and a selected storm frequency, obtain the rainfall intensity from Appendix C. The storm rainfall, P is equivalent to the product of rainfall intensity and storm duration D.

$$P = i \times D$$

6. From the storm rainfall P obtained, determine the runoff volume, q, from Figure B.2.

7. Estimate the peak runoff rate Q by using the equation

$$Q = \frac{0.00208 \times A \times q}{(0.5 \times D) + (0.6 \times Tc)}$$

This method is not recommended for use on watershed basins larger than 500 hectares.

EXAMPLE 1 **SCS METHOD**

The same example as the rational method will be used.

1. The watershed area (drainage basin) = 100 ha

2. Runoff Curve number

   From Table B.3 - Select Soil Group C

   From Table B.4 - Select Runoff Curve - based on very poor conditions and a soil group C, the runoff curve number for the wooded area is 86 - pasture is also 86. The average value is therefore 86.

   From Figure B.1 - Adjusting from an antecedent moisture condition II to III, for the Abbotsford area - the runoff curve number is adjusted from 86 to 97.

3. Time of Concentration - From Rational Method example

   Tc = 42.5 minutes = 0.71 hrs.

4. Storm Duration D = 0.7 x Tc = 0.7 x 0.71 = 0.50 hrs.

5. Rainfall Intensity From Figure C.3 Appendix C, using a duration of 0.5 hr and a 10 year frequency storm the rainfall intensity is 27 mm/hr

   Storm Rainfall $P = i \times D$

   $= 27 \frac{mm}{hr} \times 0.5\ hr = 13.5\ mm$

6. Runoff Volume q - From Figure B.2 for a value of P = 13.5 mm and a runoff curve number of 97 q = 8.0 mm

7. Peak runoff rate $Q = \frac{0.00208 \times A \times q}{(0.5 \times D) + (0.6 \times Tc)}$

   $= \frac{0.00208 \times 100 \times 8.0}{(0.5 \times 0.5) + (0.6 \times 0.71)}$

   $Q = 2.46\ m^3/sec$

The calculation of peak runoff uses several subjective decisions. It is recommended that both the rational and SCS methods be used to calculate peak runoff. If the two methods don't provide close to the same result, the various parameters should be reviewed and the peak flow recalculated. In this case the values calculated were:

Rational method - 2.65 m^3/sec
SCS method - 2.46 m^3/sec
The surface drainage design should be based on approximately 2.5 m^3/sec peak runoff.

Table B.3 Hydrologic Soil Groups (SCS Method)*

Group A (lowest runoff potential) includes deep sands with very little silt and clay, as well as deep rapidly permeable loess.

Group B comprises mostly sandy soils shallower than A, and loess less deep or less aggregated than A: but the group as a whole has above-average infiltration after thorough wetting.

Group C comprises shallow soils and soils containing considerable clay and colloid, though less than those of group D. The group has below-average infiltration after presaturation

Group D (highest runoff potential) includes mostly clays of high swelling percent, but the group also includes some shallow soils with nearly impermeable subhorizons near the surface.

Hydrologic Conditions

Classification of Pasture or Range

Hydrologic Condition	Vegetative Condition
Poor	Heavily grazed, no mulch, or has plant cover on less than 50% of the area
Fair	Moderately grazed, about 50 to 75% of the area has plant cover
Good	Lightly grazed, more than about 75% of the area has plant cover

Classification of Woodlands

Hydrologic Condition	Vegetative Condition
Poor	Heavily grazed or regularly burned so that litter, small trees and brush are destroyed
Fair	Grazed but not burned: there may be some litter but these woodlands are not fully protected from grazing
Good	Protected from grazing so that litter and shrubs cover the soil

Crop rotations range from "poor" to "good" in proportion to the amount of dense vegetation in the rotation. "Poor" rotations (from a hydrologic standpoint) contain row crops, small grains, and fallow in various combinations. "Good" rotations contain a high proportion of alfalfa or other close-seeded legumes or grasses that will improve tilth and increase infiltration.

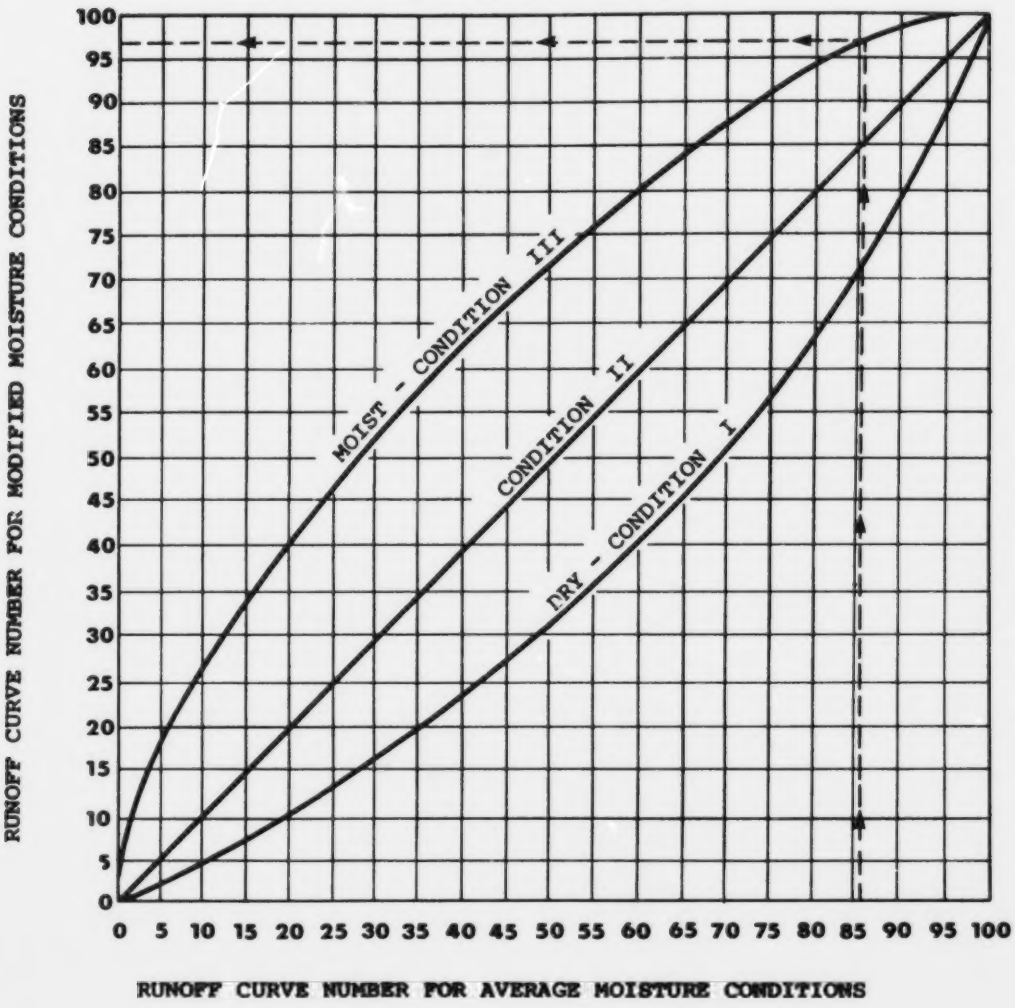
*From U.S. Soil Conservation Service

Table B.4 Runoff Curve Number for Hydrologic Soil-cover Complexes
(SCS Method)
(Antecedent Moisture Condition II)

Land Use or Cover	Treatment or Practice	Hydrologic Condition	Hydrologic Soil Group A	B	C	D
Fallow	Straight Row	-	77	86	91	94
Row Crops	Straight Row	Poor	72	81	88	91
		Good	67	78	85	89
	Contoured	Poor	70	79	84	88
		Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
		Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
		Good	63	75	83	87
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	Contoured and terraced	Poor	61	72	79	82
		Good	59	70	78	81
Close-seeded legumes* or rotation meadow	Straight row	Poor	66	77	85	89
		Good	58	72	81	85
	Contoured	Poor	64	75	83	85
		Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
		Good	51	67	76	80
Pasture or Range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
		Fair	25	59	75	83
		Good	6	35	70	79
Meadow (permanent)		Good	30	58	71	78
Woods and forests		Very poor	56	75	86	91
		Fair	36	60	73	79
		Very good	15	44	54	61
Farmsteads			59	74	82	86
Roads**(dirt)			72	82	87	89
(hard)			74	84	90	92

* Close-drilled or broadcast
** Including right-of-way

From U.S. Soil Conservation Service


RUNOFF CURVE NUMBER FOR MODIFIED MOISTURE CONDITIONS
RUNOFF CURVE NUMBER FOR AVERAGE MOISTURE CONDITIONS
MOIST - CONDITION III
CONDITION II
DRY - CONDITION I
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

DIRECT RUNOFF, q (mm)

Estimation of Antecedent Moisture Conditions

5-Day Antecedent rainfall, mm		Watershed Condition
Growing Season	Dormant Season	
Under 35 mm	Under 10 mm	I
35 to 55 mm	10 to 30 mm	II
Over 55 mm	Over 30 mm	III

Figure B.1 Runoff Curve Number (SCS Method)

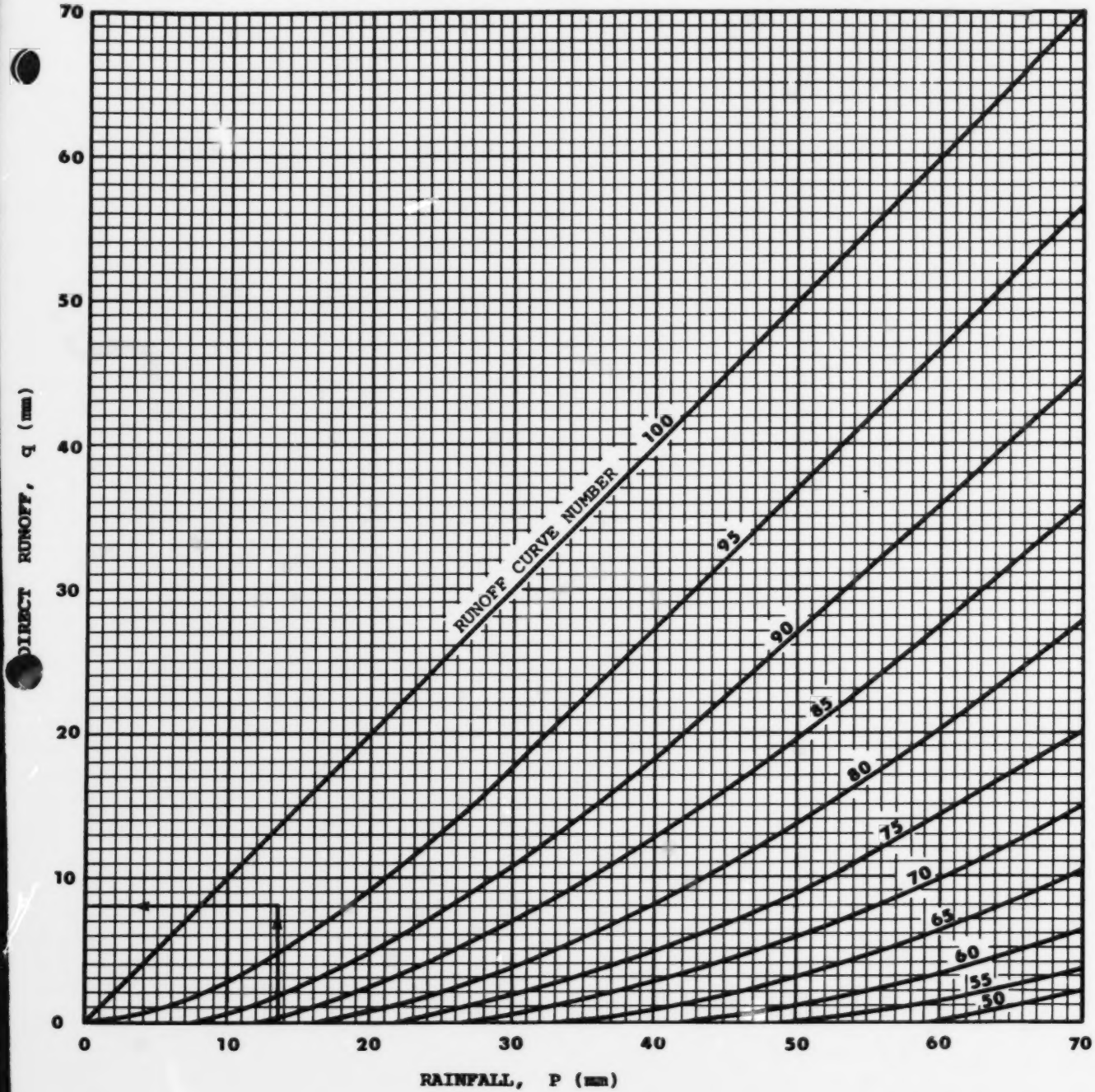


Figure B.2 Direct Runoff, q (mm) (SCS Method)

APPENDIX C

Figure C.1 **RAINFALL INTENSITY CURVES FOR**

SOUTH EAST VANCOUVER ISLAND

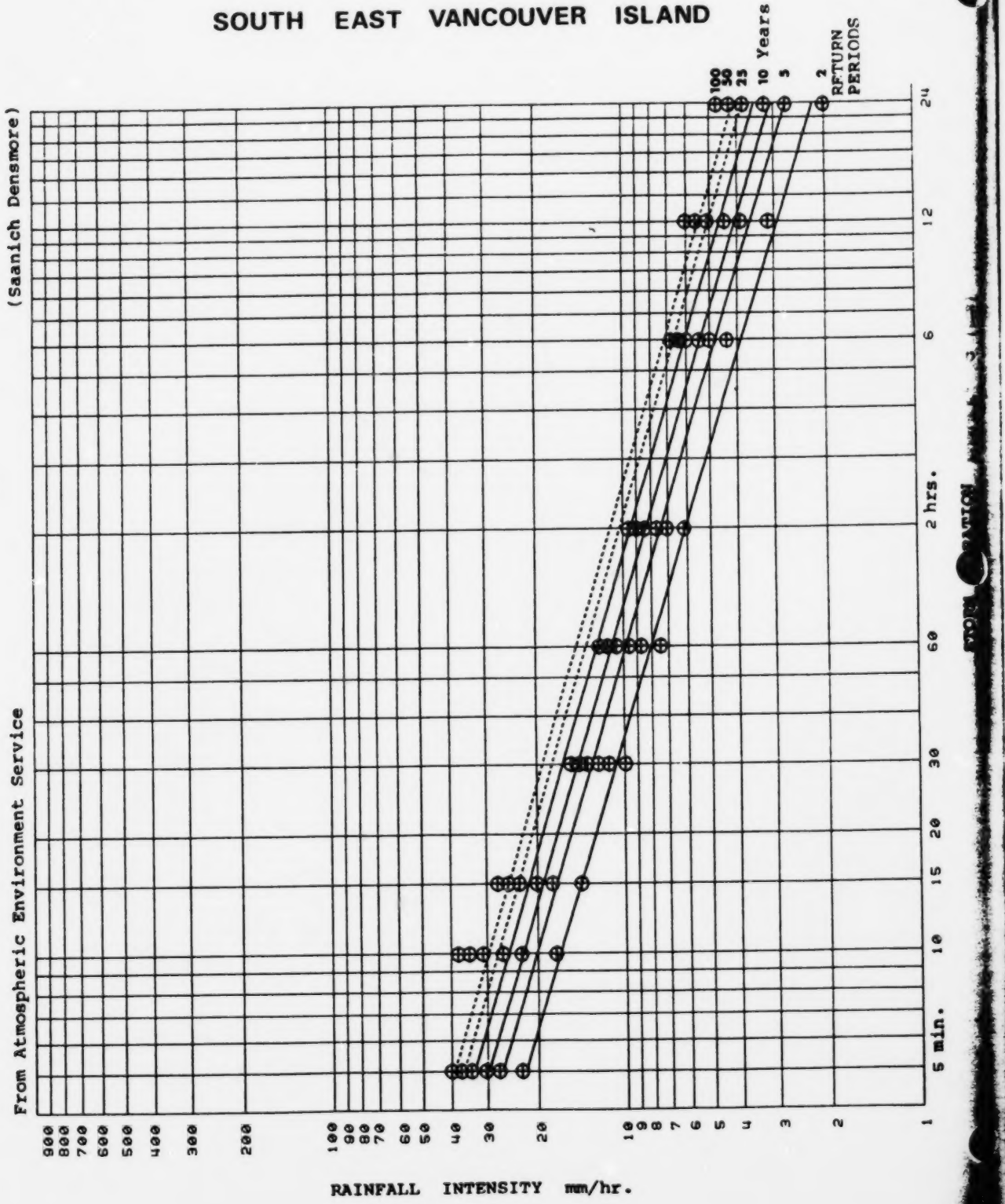


Figure C.2

RAINFALL INTENSITY CURVES FOR

LOWER FRASER VALLEY

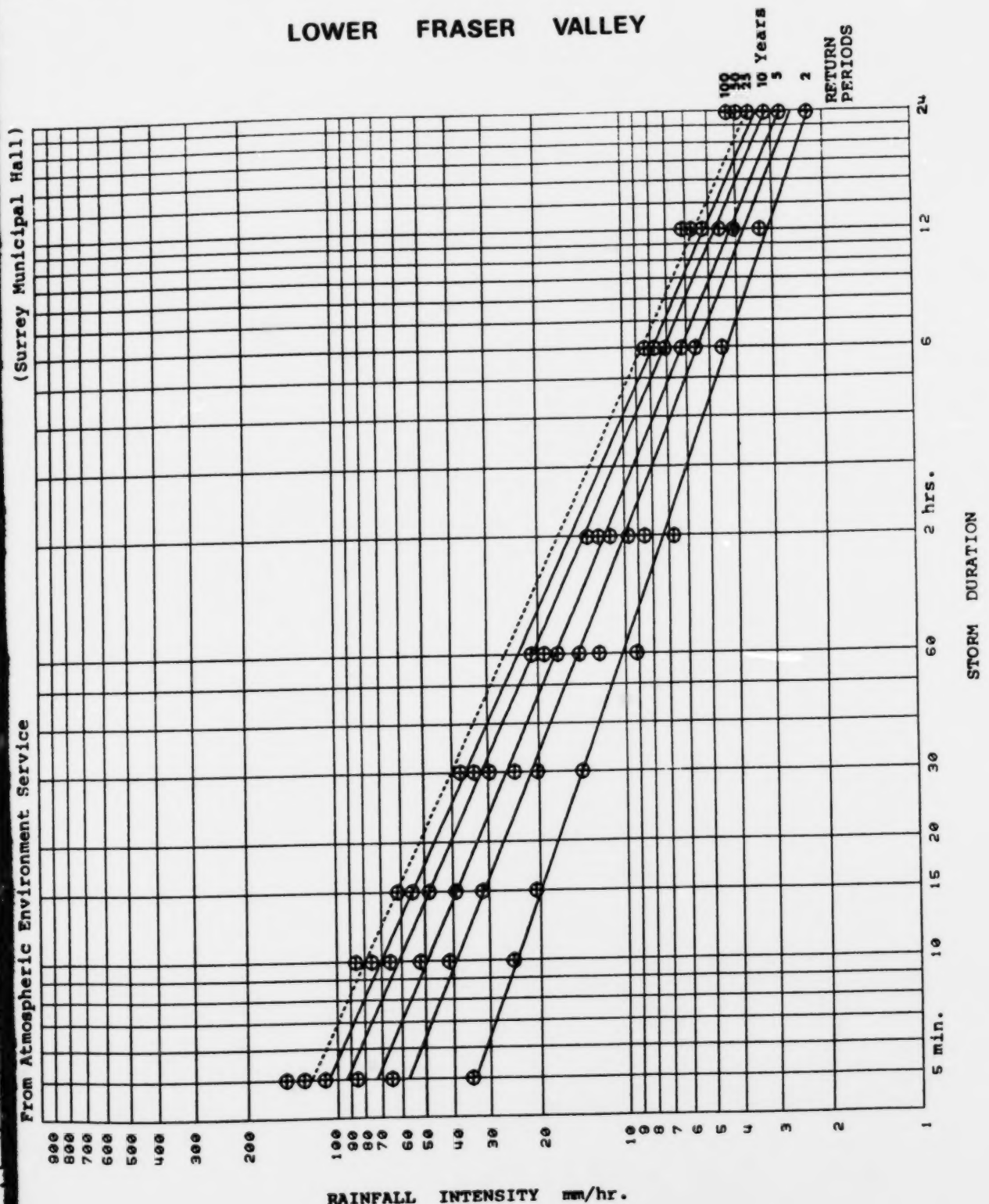


Figure C.3

RAINFALL INTENSITY CURVES FOR CENTRAL FRASER VALLEY

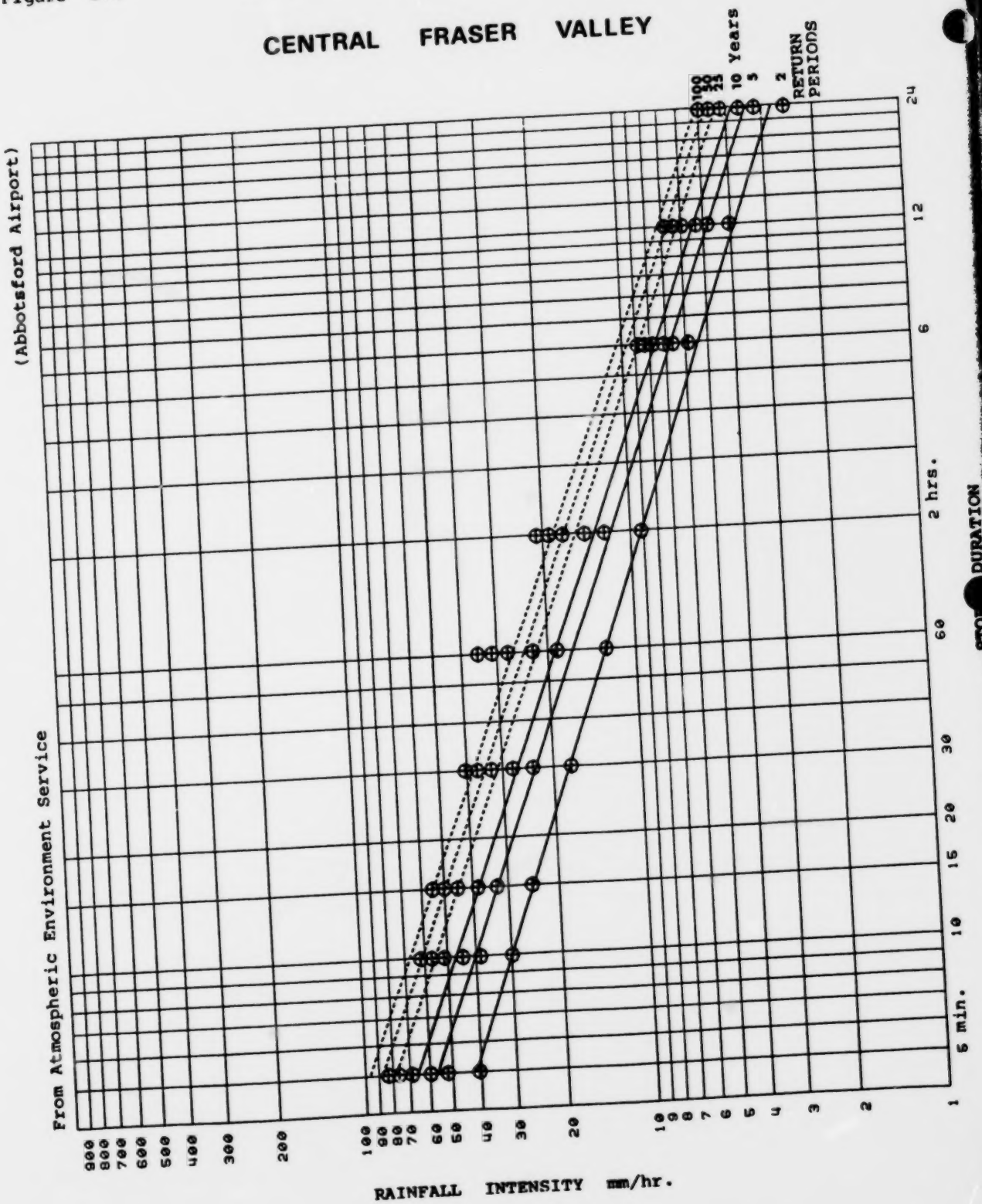


Figure C.4

RAINFALL INTENSITY CURVES FOR

OKANAGAN VALLEY

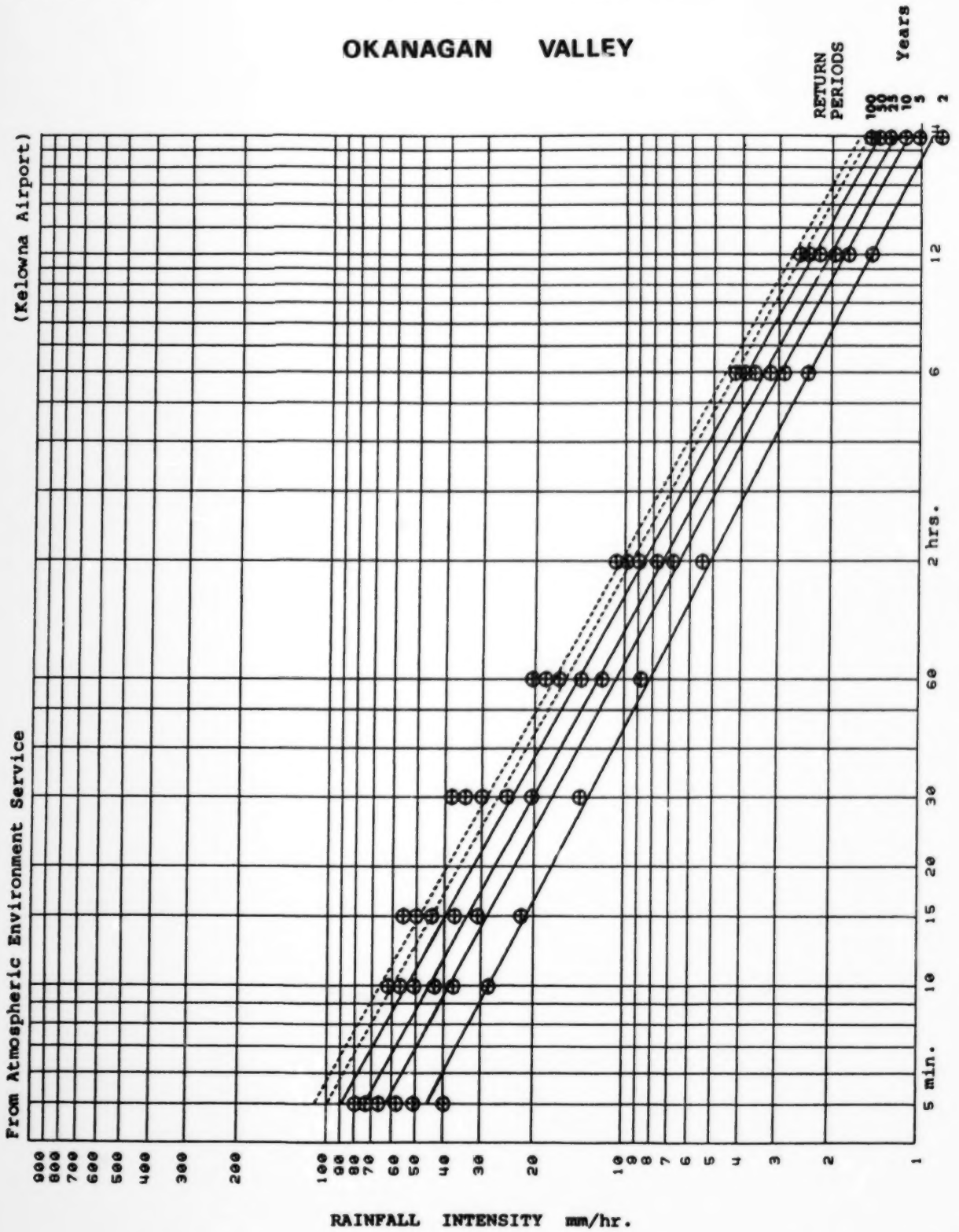


Figure C.5

RAINFALL INTENSITY CURVES FOR

SOUTH EAST B.C.

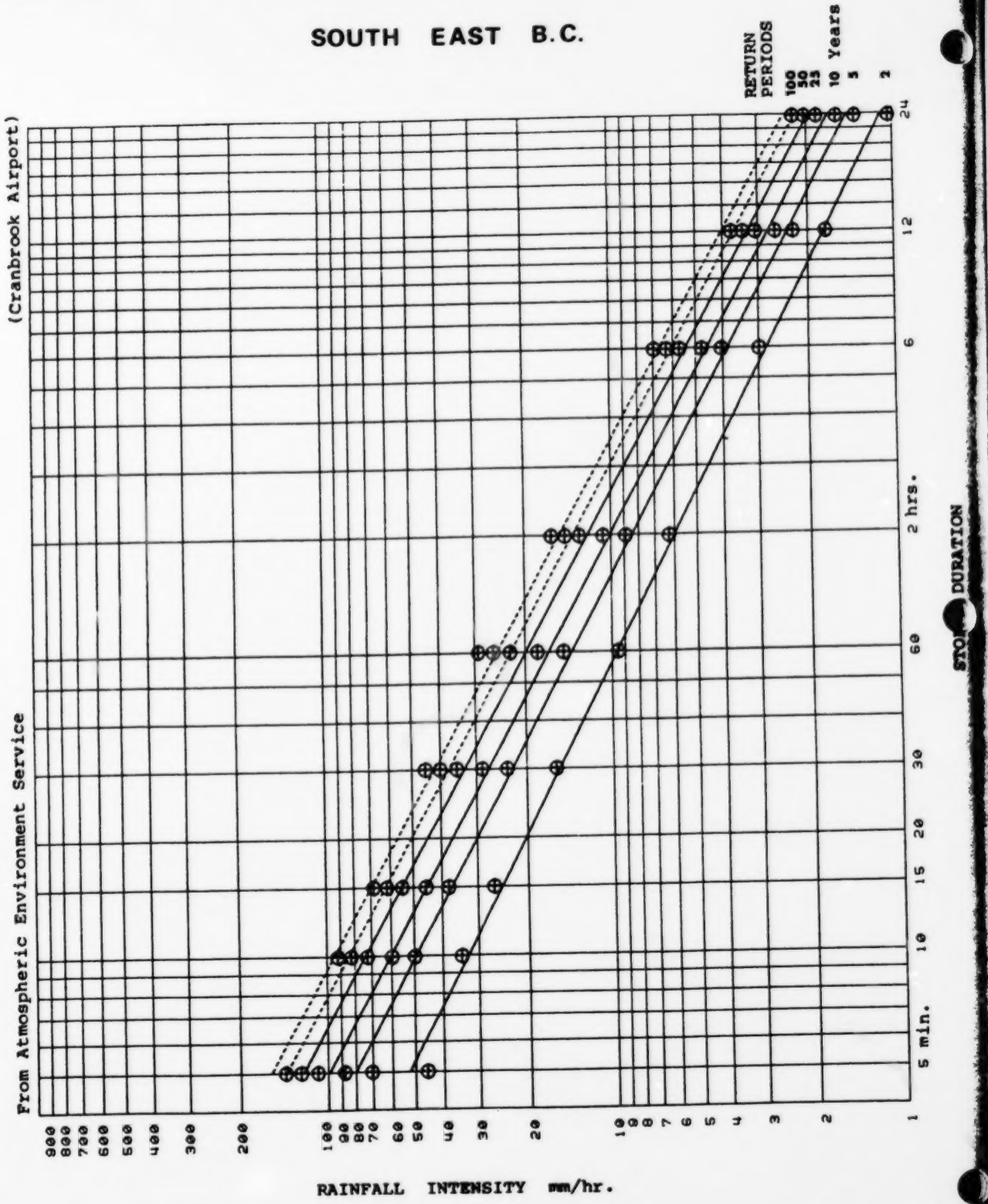


Figure C.6 **RAINFALL INTENSITY CURVES FOR**

CENTRAL INTERIOR B.C.

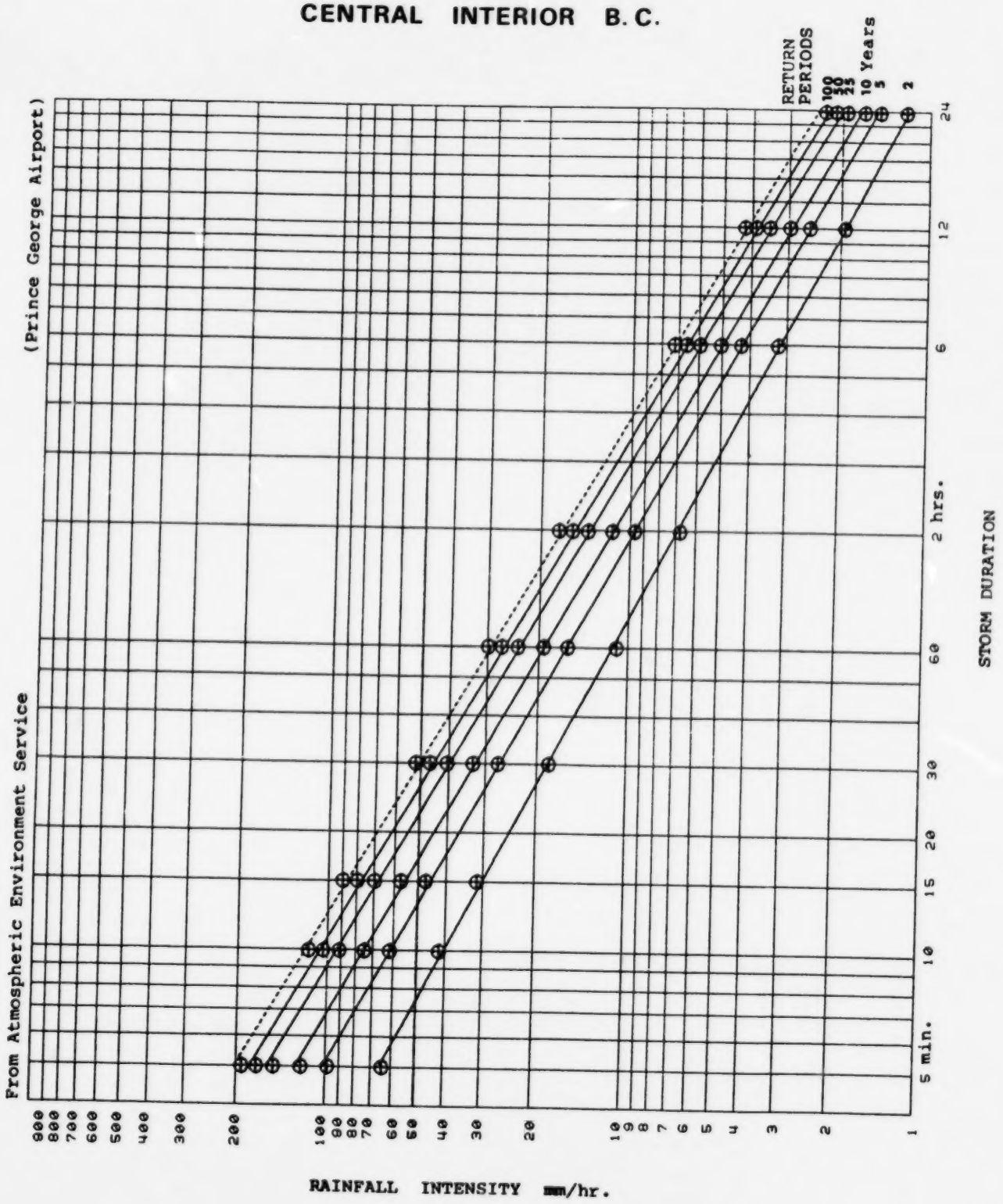
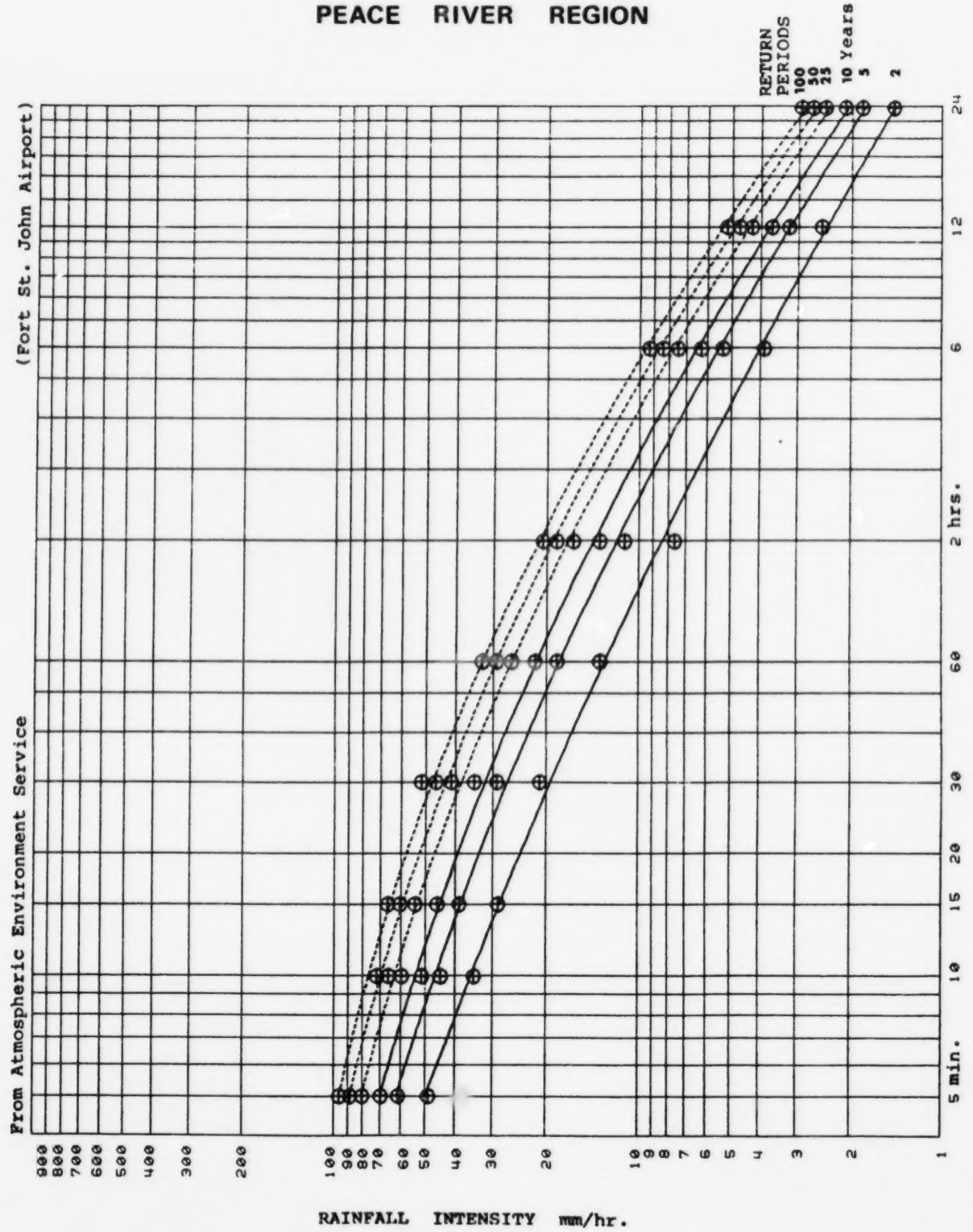


Figure C.7

RAINFALL INTENSITY CURVES FOR

PEACE RIVER REGION



APPENDIX D

Table D.1 FRICTION LOSS 14 GAUGE AGED STEEL PIPE

Friction Loss in m per 100m of Pipe

FLOW litres/sec	Nominal Pipe Size (mm) 100	125	150	200	250	300	350	400
10	1.83	.59	.24					
15	4.06	1.26	.53	.13				
20	6.98	2.24	.88	.21	.07			
25	10.51	3.38	1.36	.32	.11			
30	15.10	4.79	1.91	.46	.15	.06		
35		6.47	2.60	.62	.20	.08	.04	
40		8.32	3.35	.80	.25	.11	.05	
45		10.38	4.17	.98	.31	.14	.07	.04
50			5.06	1.20	.39	.16	.08	.05
60			7.20	1.71	.57	.23	.10	.06
70			9.66	2.32	.76	.30	.14	.07
80				2.98	.97	.39	.18	.08
90				3.66	1.20	.48	.22	.12
100				4.47	1.47	.59	.27	.14
110				5.37	1.76	.72	.33	.17
120				6.35	2.10	.83	.39	.21
130				7.45	2.48	.96	.47	.25
140				8.61	2.86	1.12	.54	.29
150					3.24	1.28	.61	.32
175					4.29	1.72	.81	.42
200					5.50	2.22	1.03	.54
250					8.40	3.40	1.59	.82
300						4.80	2.36	1.16
350						5.80	3.02	1.56
400							3.88	2.00
450							4.84	2.49
500							5.90	3.04
550								3.65
600								4.31

Based on C = 100

Conversion 1 m of water = 9.8 kilopascals.

*Flow rates below heavy lines exceed 2.25 m/sec flow Velocity and should therefore be avoided.

APPENDIX D

Table D.2 FRICTION LOSS CLASS 160 PVC PLASTIC PIPE

Friction Loss in m per 100 m of Pipe

Flow Litres/sec	Nominal Pipe Size (mm) 100	125	150	200	250	300
5	.32	.12	.05			
10	1.15	.41	.08	.05		
15	2.44	.86	.38	.10	.04	
20	4.14	1.57	.64	.18	.05	.02
25	6.24	2.22	.95	.27	.09	.04
30	8.74	3.12	1.33	.37	.13	.06
35	11.62	4.15	1.78	.49	.16	.07
40	14.91	5.32	2.28	.64	.22	.09
45		6.62	2.82	.79	.27	.12
50		8.03	3.43	.95	.32	.14
60		11.25	4.80	1.34	.46	.21
70			6.40	1.78	.61	.26
80			8.20	2.27	.77	.33
90			10.18	2.82	.96	.43
100				3.43	1.18	.45
110				4.09	1.40	.61
120				4.80	1.64	.72
130				5.61	1.91	.83
140				6.47	2.20	.97
150				7.32	2.50	1.10
175					3.33	1.45
200					4.25	1.85
225					5.26	2.30
250					6.40	2.80
275						3.33
300						3.92

Based on C = 150

Conversion 1 m of water = 9.8 kilopascals

*Flow rates below heavy lines exceed 2.25 m/sec flow velocity and should therefore be avoided.

APPENDIX E

CONVERSION TABLE (METRIC TO IMPERIAL)

Flow

1 litre per second	=	15.85	gallons per minute (U.S.)
1 litre per second per hectare	=	6.4	gallons per minute per acre
1 cubic meter per second	=	35.3	cubic feet per sec.

Volume

1 litre (l)	=	0.264	gallons (U.S.)
	=	0.220	gallons (Imperial)
1 cubic meter	=	264	gallons (U.S.)
	=	35.3	cubic feet
	=	0.000811	acre feet

Area

1 hectare (ha)	=	2.47	acres
	=	10,000	square meters

Length

1 meter (m)	=	3.28	feet
	=	39.37	inches
	=	1000	millimeters
1 kilometer (km)	=	1000	meters
	=	3280	feet
	=	0.621	mile

Pressure

1 kilopascal (kPa)	=	0.145	pounds per square inch (psi)
	=	0.10	m of head of water
1 m of water	=	9.8	kilopascals
1 bar	=	100	kilopascals
	=	0.98	atmospheres
	=	14.5	pounds per square inch

Drainage Coefficients

1 litre per sec per hectare	=	0.34	inches per day
1 mm per day	=	0.743	gpm (U.S.) per acre

Energy

1 Kilowatt (kW)	=	1.34	horsepower (h.p.)

GLOSSARY

Drain	Conduit below the ground surface for removal of surplus ground or surface water
Drainage Area	Area from which drainage water is collected and delivered to an outlet.
Drainage Coefficient (Drainage Rate)	The depth of water to be removed from an area in 24 hours.
Equivalent depth, de	The equivalent depth (de) is a function of the drain spacing, drain tube radius and depth (d) to the impermeable layer below the drain centers. It is the effective flow through the soil below the drains. Hooghoudt has suggested the use of de to replace the actual depth to the impermeable barrier as a means of accounting for the physical convergence of flow lines near the drain.
Grade	Degree of slope of a channel or natural ground.
Hydraulic Conductivity	A numerical value for soil permeability (measured in m/day).
Hydraulic Radius	The ratio of the water area to the wetter perimeter
Impermeable Layer	If the permeability of the subsoil is about one-tenth that of the surface soil it can be considered impermeable from a drainage standpoint.
Slope	Degree of deviation of a surface from the horizontal. (Expressed as a percent or ratio of horizontal to vertical, i.e. 2:1).
Total Dynamic Head	Energy equal to the sum of static lift, friction head, static discharge head and velocity head.
Time of Concentration	The time taken for storm runoff to travel from the furthest point of the basin to the site in question.
Velocity Head	The Kinetic energy per unit weight of water = $v^2/2g$.
Water Area	The flow cross-sectional area perpendicular to the direction of the flow.
Watershed	Total land area above a given point on a stream or waterway that contributes runoff to that point.
Wetted Perimeter	The sectional length of the wetted surface in contact with the flow.

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